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THE BINARY SYSTEM $NaPO_3$–$Na_4P_2O_7$.

GEORGE W. MOREY AND EARL INGERSON.

ABSTRACT. In the binary system $NaPO_3$–$Na_4P_2O_7$ there is a eutectic, at 552° and 0.81 weight fraction $Na_4P_2O_7$, at which the crystalline phases are $NaPO_3$ and $Na_5P_3O_{10}$, the only binary compound between the two end members. $Na_5P_3O_{10}$ melts incongruently at 622°, forming crystals of $Na_4P_2O_7$ and liquid containing 0.495 weight fraction $Na_4P_2O_7$. Optical properties of these three compounds are given.

THE system Na_2O–P_2O_5 resembles the systems Na_2O–SiO_2[1] and Na_2O–B_2O_3[2] in that at the high-alkali end the ortho-compounds crystallize readily; in the intermediate portions glasses are formed which can be crystallized without difficulty to a series of sodium phosphates; and in mixtures low in sodium oxide the tendency toward glass formation greatly increases. Previous studies have made clear the phase equilibrium relationships in the systems with SiO_2 and with B_2O_3, and it was our plan to carry on a similar study in this system. However, other duties have made it necessary to abandon this project, and this paper is a report on the intermediate portion of the system, from the pyrophosphate, $Na_4P_2O_7$ or $2Na_2O.P_2O_5$, to the metaphosphate, $NaPO_3$ or $Na_2O.P_2O_5$. In another paper[3] we have summarized the optical properties of sodium phosphates and sodium phosphate hydrates.

Compounds outside of the range from metaphosphate to pyrophosphate have been described. Excellent crystals of sodium orthophosphate, Na_3PO_4, were obtained by Schroeder, Berk, and Gabriel[4] in studies of solubility in water under pressure. We have prepared it in an impure state by heating $Na_4P_2O_7$ and Na_2CO_3 at 1400°. Rapid loss of P_2O_5 prevented

[1] Morey, G. W., and Bowen, N. L.: 1924, Jour. Phys. Chem., 28, 1167-1179; Kracek, F. C.: 1930, ibid., 34, 1583-1598.

[2] Morey, G. W., and Merwin, H. E.: 1936, Jour. Amer. Chem. Soc., 58, 2248-2254.

[3] Ingerson, Earl, and Morey, G. W.: 1943, Amer. Mineral., 448-455.

[4] Schroeder, W. C., Berk, A. A., and Gabriel, A.: 1937, Jour. Amer. Chem. Soc., 59, 1783.

our determination of its apparently high melting point. When $Na_3PO_4.H_2O$ was heated 16 hours at 600° it appeared to be isotropic; heated 30 minutes at 1400° it remained essentially isotropic with index about 1.487. More study is needed in this region of the diagram.

Another part of the system yet to be studied is that from $NaPO_3$ to P_2O_5. Diphosphates of other bases exist, and a sodium diphosphate, $Na_2O.2P_2O_5$, is to be expected. The compound variously formulated as $NaH_5(PO_4)_2$, or $NaH_2PO_4.H_3PO_4$, or $Na_2O.2P_2O_5.5H_2O$, commonly found in commercial glacial phosphoric acid, may be a diphosphate.

The experimental results were all obtained by the quenching method, which has often been described in papers from this Laboratory. A small amount of the powdered material, about 10 mg., wrapped in platinum foil 0.01 mm. thick, is held at constant temperature long enough for equilibrium to be reached; cooled at such a rate as to freeze that equilibrium; and examined with the petrographic microscope. If all glass, the temperature of treatment was above the liquidus; the presence of crystals indicates that the temperature was below the liquidus; and by successive approximations the liquidus temperature can be located as closely as desired. Moreover, the primary phase, that is, the crystalline phase which separates at the liquidus, can be positively identified by its optical properties, thus leaving no doubt as to the interpretation of the results. This method was particularly suitable for investigating the region from $NaPO_3$ up to 55 per cent $Na_4P_2O_7$. With higher content of $Na_4P_2O_7$, crystallization takes place so readily that the thermal method is more suitable. At the liquidus for the composition of $Na_5P_3O_{10}$ it was necessary to weight the charge and drop into mercury, and it was not possible to prepare glass of the composition of $Na_4P_2O_7$. We have accepted the melting point of 985° determined by Partridge, Hicks, and Smith[5] for $Na_4P_2O_7$.

The thermocouples used were calibrated at the melting points of aluminum (B. S. Standard Sample No. 44c, melting point 660.1), potassium chloride, 770.3°, and sodium chloride,[6] 800.4°, and the calibrated points were used in connection with a deviation curve for interpolation in the standard tables of

[5] Partridge, E. P., Hicks, Victor, and Smith, G. W.: 1941, Jour. Amer. Chem. Soc., 63, 454-466.

[6] Roberts, H. S.: 1924, Phys. Rev., 23, 386-395.

TABLE I.

Phase Equilibrium Data for the System $NaPO_3$–$Na_4P_2O_7$.

Weight Fraction $Na_4P_2O_7$	Liquidus °C.	Primary Phase	Incongruent Melting Temperature °C.	Eutectic Temperature °C.
0	627.6	$NaPO_3$	...	...
0.15	607	$NaPO_3$	...	552
0.33	557	$Na_5P_3O_{10}$	...	552
0.40	586.5	$Na_5P_3O_{10}$	...	552
0.45	603	$Na_5P_3O_{10}$	...	...
0.475	615.5	$Na_5P_3O_{10}$	...	...
0.50	631	$Na_4P_2O_7$	622	...
0.5659	704	$Na_4P_2O_7$	622	552
0.57	711	$Na_4P_2O_7$	622	...
0.60	743	$Na_4P_2O_7$	...	...
0.66	801	$Na_4P_2O_7$	...	...
0.72	880	$Na_4P_2O_7$	622	...
(1.00)	(985)			

Adams.[7] The quenching results are given in Table I, and the phase equilibrium diagram in Fig. 1.

The binary system $NaPO_3$–$Na_4P_2O_7$ has been studied by Parravano and Calcagni,[8] Huber,[9] Andress and Wüst,[10] and Partridge, Hicks, and Smith.[11] Parravano and Calcagni found no intermediate compound, but the more recent investigators agree on the formation of sodium tripolyphosphate, $Na_5P_3O_{10}$, or $5Na_2O.3P_2O_5$. Partridge, Hicks, and Smith established the fact that $Na_5P_3O_{10}$ has an incongruent melting point, decomposing to $Na_4P_2O_7$ and liquid. Our results agree closely with theirs, except in the region from the eutectic to the incongruent melting, and in addition we have determined the difference between the forms of $Na_5P_3O_{10}$ and two forms of $NaPO_3$. The $NaPO_3$ III of Partridge, Hicks, and Smith was not obtained by us.

Sodium metaphosphate, $NaPO_3$, affords a convenient secondary standard substance for calibration of thermocouples. It can easily be obtained pure by dehydration of $NaH_2PO_4.H_2O$. The glass resulting from fusion is stable, crystallizes promptly on heating to just below the melting point, and the melt undercools

[7] Adams, L. H.: 1926, International Critical Tables, vol. 1, 57-59, McGraw-Hill, New York.

[8] Parravano, N., and Calcagni, G.: 1910, Z. anorg. Chem., 65, 1-9.

[9] Huber, Hans: 1937, Z. angew. Chem., 50, 323-326.

[10] Andress, K. R., and Wüst, K.: 1938, Z. anorg. Chem., 237, 113-131; 1939, ibid., 241, 196-204.

[11] Partridge, E. P., Hicks, Victor, and Smith, G. W.: op. cit.

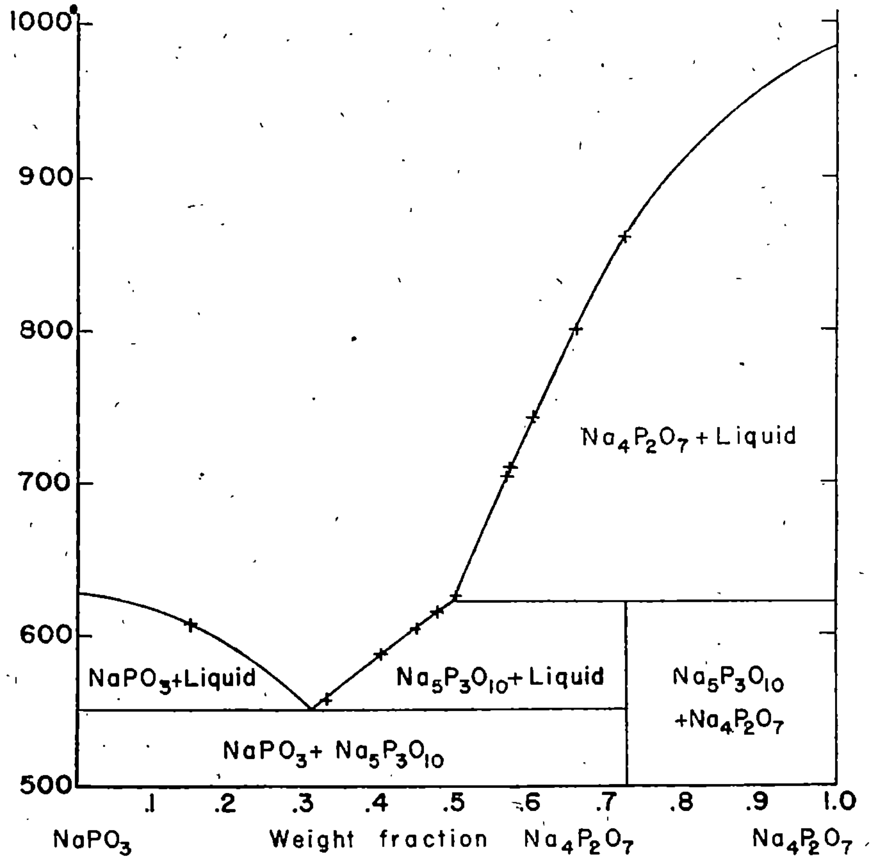

Fig. 1. Phase equilibrium diagram for the system $NaPO_3$–$Na_4P_2O_7$.

so readily that it can be quenched merely by lifting from the furnace. The melting temperature, 627.6,° fills in a gap in the series of secondary standards.

The discussion of the forms of $NaPO_3$ is made more difficult by the persistence of the now absurd system of nomenclature devised almost one hundred years ago by Fleitmann and Henneberg,[12] which not only has no justification in modern theory but also is in conflict with modern knowledge of the structure of glasses. The glassy form, called "sodium hexametaphosphate," and formulated as $(NaPO_3)_6$, is but one of a continuous series of glasses in which the assumption of definite compounds is in conflict with modern theories of the structure of

[12] Fleitmann, Th., and Henneberg, W.: 1848, Ueber phosphorsäure Salze: Liebig's Annalen der Chemie, 65, 304–384.

glass, and the identification of six as the degree of polymerization is without justification.

Sodium metaphosphate exists in at least two crystalline forms. $NaPO_3$ I is obtained by crystallizing just below the melting point. It is biaxial, negative, 2V 80°, α1.474, β1.478, γ1.480. $NaPO_3$ II may be obtained by crystallizing the glass at about 450°. It is probably orthorhombic, and is biaxial, positive, 2V 78°, α1.498, β1.510, γ1.529. The relation between the two forms is not clear. The glass has index 1.4847.

At the binary eutectic, 552° and 0.31 weight fraction $Na_4P_2O_7$, the crystalline phases are $NaPO_3$ and $Na_5P_3O_{10}$, the only compound between the two end-members. It exists in two forms. The high-temperature form, I, is biaxial, positive, 2V 21°, α1.477, β1.478, γ1.504. It was obtained when the melt was quickly cooled to room temperature from about 600°. When the crystallized melt was cooled in the furnace it inverted to the II-form, with spontaneous powdering. $Na_5P_3O_{10}$ II is biaxial, positive, 2V 57°, α1.470, β1.477, γ1.502. Glass of this composition has index 1.4814.

$Na_5P_3O_{10}$ melts incongruently at 622° to form crystalline $Na_4P_2O_7$ and a melt of composition $0.505NaPO_3$, $0.495Na_4P_2O_7$. This melting is very sharp. The pure compound shows no sintering at 620°, much glass and $Na_4P_2O_7$ at 623°. In contrast, a melt containing $0.5659Na_4P_2O_7$ was so sintered at 556° that grinding with mortar and pestle was necessary to obtain a powder, but it was difficult to find the glass under the microscope. This was because each individual crystal of $Na_5P_3O_{10}$ was surrounded by a film of glass so that the true index could not be observed until these individuals were crushed; and the difference in index between glass and the low index of the crystals is so small that the presence of glass could be detected only after careful search. After it was found and its habit had been observed it could be found in every grain, and the properties of the crystals confirmed their identification as $Na_5P_3O_{10}$.

Glass of this composition can be obtained only by rapid and careful quenching. Nevertheless, the liquidus temperature can be determined with greater certainty by the quenching method than by the heating curve method because of the steepness of the melting point curve at this point.

SUMMARY.

A redetermination of the phase equilibrium relationships in the binary system $NaPO_3$–$Na_4P_2O_7$ in general confirms the work of Partridge, Hicks, and Smith. The region between the binary eutectic and $Na_5P_3O_{10}$ has been more precisely located, and the properties of the crystalline compounds were precisely determined.

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A FORAMINIFERAL FAUNA OF THE WILCOX EOCENE, BASHI FORMATION, FROM NEAR YELLOW BLUFF, ALABAMA.*

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ABSTRACT. Comparatively little is known of the foraminifera of the American Wilcox Eocene. The material from Yellow Bluff, Ala., adds somewhat to the known fauna of the Bashi formation and indicates that certain species may be used as index fossils for this part of the Wilcox Eocene. One new species and a new variety are described.

SEVERAL papers in the last few years have given considerable information on the foraminiferal faunas of various formations of the Eocene Wilcox group. This part of the Eocene has been rather neglected in comparison with the Claiborne and Jackson groups and with the Paleocene Midway group.

The fauna of the type locality of the Bashi formation, Woods Bluff, Tombigbee River, Alabama, was published by Cushman and Garrett, 1939 (Contr. Cushman Lab. Foram. Res., Vol. 15, pp. 77-89, Pls. 13-15). A Wilcox fauna representing the Tuscahoma sand from 1 mile N. of Ozark, Alabama, was published by Cushman and Ponton, 1932 (l. c., Vol. 8, pp. 51-72, Pls. 7-9). A fauna from the Salt Mountain limestone of Alabama was published by Toulmin, 1941 (Journ. Pal., Vol. 15, pp. 567-611, Pls. 78-82, Text Figs. 1-4).

The material used here is from the Bashi formation, collected by Dr. C. G. Lalicker, secs. 13 and 24, T. 11 N., R. 5 E., 4½ miles SE. of Yellow Bluff, west bank of Alabama River, Wilcox Co., Alabama. This fauna adds somewhat to the previous Bashi records and confirms those species already recorded. The fauna indicates that it is not from a very shallow habitat but of medium depth.

The figures are all of the same magnification for convenience in comparison. A number of the species, from the records, seem to be index fossils for this part of the Wilcox Eocene and should be useful in correlation.

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Family TEXTULARIIDAE.

Genus SPIROPLECTAMMINA Cushman, 1927.

Spiroplectammina wilcoxensis Cushman and Ponton (Pl. 1, Figs. 1, 2).

Spiroplectammina wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 51, Pl. 7, Fig. 1.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 78, Pl. 13, Figs. 1, 2.—Toulmin, Journ. Pal., Vol. 15, 1941, p. 571, Pl. 78, Fig. 1.

The types of this species are from the Wilcox Eocene, one mile N. of Ozark, Alabama. It is also recorded from the Bashi formation of Woods Bluff, Alabama. Toulmin records it from the Salt Mountain limestone, Bashi and Hatchetigbee formations of Alabama, and the Vincentown sand of New Jersey. He also notes its occurrence in the Nanafalia and Tuscahoma formations of Alabama. Typical specimens occur in the Bashi material.

Family LAGENIDAE.

Genus ROBULUS Montfort, 1808.

Robulus sp. (Pl. 1, Fig. 3).

Rare specimens, probably young, occurred, but cannot be specifically determined. They may be the young stages of *R. wilcoxensis* Cushman and Ponton.

Genus MARGINULINA d'Orbigny, 1826.

Marginulina sp. (Pl. 1, Fig. 4).

Several specimens, all young megalospheric forms, occurred but are not specifically identifiable without more material.

Genus DENTALINA d'Orbigny, 1826.

Dentalina wilcoxensis Cushman, n. sp. (Pl. 1, Figs. 5, 6).

Dentalina sp. Cushman and Todd, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 30, Pl. 5, Fig. 20.

Test small, elongate, of nearly uniform diameter throughout, circular or slightly compressed in transverse section, rounded at the initial end; chambers few, slightly if at all inflated, increasing only slightly in height as added; sutures distinct but not depressed, strongly oblique; wall smooth; aperture terminal, rounded, with the border finely toothed. Length 0.50 mm., diameter 0.10-0.12 mm.

Holotype (Cushman Coll. No. 39230) from the Wilcox Eocene, Bashi formation, 4½ miles SE. of Yellow Bluff on west bank of Alabama River at old ferry landing, Wilcox County, Alabama.

This species differs from *Dentalina mucronata* Neugeboren in the higher and fewer chambers and less tapering test. It occurs also in the Paleocene Naheola formation at its type locality, Naheola Landing, on Tombigbee River, Choctaw County, Alabama, as figured in the above reference.

Family POLYMORPHINIDAE.

Genus GUTTULINA d'Orbigny, 1839.

Guttulina problema d'Orbigny, var. arcuata Cushman, n. var. (Pl. 1, Fig. 7).

Variety differing from the typical in the smaller size, more pointed base, and more lobate form.

Holotype of variety (Cushman Coll. No. 39233) from the Wilcox Eocene, Bashi formation, 4½ miles SE. of Yellow Bluff, on west bank of Alabama River at old ferry landing, Wilcox County, Alabama.

A comparison of this form with topotypes of the typical form from the Miocene of Austria shows that the two are distinct.

Guttulina wilcoxensis Cushman and Ponton (Pl. 1, Fig. 8).

A few specimens from this Bashi locality are probably the young of this species but no adults were found.

Genus GLOBULINA d'Orbigny, 1839.

Globulina gibba d'Orbigny (Pl. 1, Figs. 9, 10).

Specimens of this species are fairly common in the Bashi material. Toulmin notes its occurrence in the Nanafalia, Tuscahoma, and Hatchetigbee formations of the Wilcox group.

Genus POLYMORPHINA d'Orbigny, 1826.

Polymorphina sp. (Pl. 1, Fig. 11).

A single specimen with definitely biserial chambers in the adult is figured. No others were found in the material. It is probably a young stage. It somewhat resembles the figures given by Toulmin (1941, Journ. Pal., Vol. 15, Pl. 80, Fig. 11) from the Salt Mountain limestone and referred to *Glandulina*

abbreviata Neugeboren, and by Cushman and Garrett (1939, Contr. Cushman Lab. Foram. Res., Vol. 15, Pl. 14, Fig. 10) from the Bashi at Woods Bluff, Alabama, but is more strongly compressed. It does not have the same shaped chambers or sutures as *Pseudopolymorphina decora* (Reuss) (Toulmin, Pl. 80, Fig. 14).

Family NONIONIDAE.

Genus NONIONELLA Cushman, 1926.

Nonionella wilcoxensis Cushman and Ponton (Pl. 1, Fig. 12).

Nonionella wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 65, Pl. 8, Fig. 12.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 82, Pl. 14, Fig. 15.—Cushman, U. S. Geol. Survey Prof. Paper 191, 1939, p. 29, Pl. 7, Fig. 13.

This species was described from the Wilcox Eocene, Tuscahoma sand, one mile N. of Ozark, Alabama. It has also been recorded from the Bashi formation, Woods Bluff, Alabama. A single specimen occurred in the material from near Yellow Bluff.

Family HETEROHELICIDAE.

Genus GÜMBELINA Egger, 1899.

Gümbelina wilcoxensis Cushman and Ponton (Pl. 1, Figs. 13, 14).

Gümbelina wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 66, Pl. 8, Figs. 16, 17.—Toulmin, Journ. Pal., Vol. 15, 1941, p. 597, Pl. 80, Fig. 24.

This species was originally described from material of Wilcox age from near Ozark, Alabama. It is recorded by Toulmin from the Salt Mountain limestone and Tuscahoma sand of Alabama. The specimens from the Bashi are typical.

Genus EOUVIGERINA Cushman, 1926.

Eouvigerina excavata Cushman (Pl. 1, Fig. 18).

Eouvigerina excavata Cushman, Contr. Cushman Lab. Foram. Res., Vol. 16, 1940, p. 66, Pl. 11, Fig. 18.—Cushman and Todd, l. c., Vol. 18, 1942, p. 35, Pl. 6, Figs. 20, 21.

A single specimen occurred in this Bashi material but is typical. The types are from the Midway Paleocene of Alabama, some material from the Naheola formation.

Genus PSEUDOUVIGERINA Cushman, 1927.

Pseudouvigerina naheolensis Cushman and Todd (Pl. 1, Figs. 15, 16).

Pseudouvigerina naheolensis Cushman and Todd, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 36, Pl. 6, Figs. 18, 19.

Typical specimens of this species, originally described from the Naheola formation, are fairly numerous in the Bashi formation. Some unusually long ones are figured here.

Family BULIMINIDAE.

Genus ROBERTINA d'Orbigny, 1846.

Robertina wilcoxensis Cushman and Ponton (Pl. 1, Fig. 17).

Robertina wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 66, Pl. 8, Fig. 19.—Cushman and Parker l. c., Vol. 12, 1936, p. 96, Pl. 16, Fig. 18.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 82, Pl. 14, Fig. 16.—Cushman and Todd, l. c., Vol. 18, 1942, p. 36, Pl. 6, Figs. 22, 23.

This species was described from the Wilcox near Ozark, Alabama. It has since been recorded from the Bashi at Woods Bluff and from the Paleocene Naheola. This is the earliest known species of the genus. It is rare in the Bashi material.

Genus VIRGULINA d'Orbigny, 1826.

Virgulina wilcoxensis Cushman and Ponton (Pl. 1, Figs. 19, 20).

Virgulina wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 67, Pl. 8, Fig. 22.—Cushman, Special Publ. No. 9, Cushman Lab. Foram. Res., 1937, p. 6, Pl. 1, Fig. 17.—Cushman and Garrett, Contr. Cushman Lab. Foram. Res., Vol. 15, 1939, p. 82, Pl. 14, Figs. 19-21.—Cushman, l. c., Vol. 16, 1940, p. 67, Pl. 11, Fig. 19.

The types of this species are from the Wilcox Eocene near Ozark, Alabama. It has also been recorded from the Wilcox, Bashi formation, of Woods Bluff, Alabama, and from the Paleocene Midway of Alabama. It is fairly common in the Bashi material.

Virgulina cf. dibollensis Cushman and Applin (Pl. 1, Fig. 21).

Rare specimens resembling this Jackson species occur in the Bashi material. They are very distinct from *V. wilcoxensis*.

Genus BOLIVINA d'Orbigny, 1839.

Bolivina cf. midwayensis Cushman (Pl. 1, Figs. 22, 23).

A few specimens from the Bashi material strongly resemble this species. They are much smaller and may be only immature specimens or may possibly be the young of *Loxostomum wilcoxense*.

Genus LOXOSTOMUM Ehrenberg, 1854.

Loxostomum wilcoxense Cushman and Ponton (Pl. 1, Fig. 24).

Loxostomum wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 67, Pl. 9, Fig. 8.—Cushman, Special Publ. No. 9, Cushman Lab. Foram. Res., 1937, p. 174, Pl. 20, Fig. 22.

The types are from the Wilcox Eocene, Tuscahoma sand, one mile N. of Ozark, Alabama. Rare specimens in the Bashi material seem to be identical.

Loxostomum sp. (Pl. 1, Fig. 25).

The figured specimen in some respects resembles *L. claibornense* Cushman but is not the same. It is probably a new species but more material is necessary to give the full characters.

Genus BIFARINA Parker and Jones, 1872.

Bifarina tombigbeensis Hadley (Pl. 1, Figs. 26-28).

Bifarina tombigbeensis Hadley, Bull. Amer. Pal., Vol. 22, No. 74, 1935, p. 8, Pl. 1, Fig. 7.—Cushman, Special Publ. No. 9, Cushman Lab. Foram. Res., 1937, p. 198, Pl. 28, Figs. 1, 2, 20.—Cushman and Garrett, Contr. Cushman Lab. Foram. Res., Vol. 15, 1939, p. 82, Pl. 14, Figs. 22, 23.

The records for this species are all from Woods Bluff, Alabama, the type locality of the Bashi formation. It is not surprising therefore to find that this is one of the more common species in the Bashi material from near Yellow Bluff. It is probably a good index fossil for this part of the Eocene.

Genus UVIGERINA d'Orbigny, 1826.

Uvigerina alabamensis Cushman and Garrett (Pl. 1, Figs. 29-31).

Uvigerina alabamensis Cushman and Garrett, Contr. Cushman Lab. Foram. Res., Vol. 15, 1939, p. 83, Pl. 14, Figs. 26, 27.

The types of this species are from the Bashi formation of the Wilcox Eocene at Woods Bluff, Alabama. It is abundant in the collection from the Bashi near Yellow Bluff, Alabama, and should, with the preceding species, make a good index fossil for this formation.

Family ROTALIIDAE.
Genus LAMARCKINA Berthelin, 1881.

Lamarckina wilcoxensis Cushman (Pl. 1, Figs. 32-35).

Lamarckina wilcoxensis Cushman, Contr. Cushman Lab. Foram. Res., Vol. 2, 1926, p. 9, Pl. 1, Fig. 8; Cushman and Ponton, l. c., Vol. 8, 1932, p. 70, Pl. 9, Fig. 4.—Glaessner, Problems of Paleontology, Moscow Univ., Vols. 2-3, 1937, p. 381, Pl. 2, Fig. 29.

The types of this species are from the Wilcox Eocene, Bashi formation, of Woods Bluff, Alabama. It was also recorded from the Tuscahoma sand, one mile N. of Ozark, Alabama. Glaessner recorded it from the Eocene of the Caucasus region. It is fairly common in the Bashi material from near Yellow Bluff.

Genus VALVULINERIA Cushman, 1926.

Valvulineria scrobiculata (Schwager) (Pl. 2, Figs. 1, 2).

Anomalina scrobiculata Schwager, Palaeontographica, Vol. 30, 1883, Pal. Theil, p. 129, Pl. 29(6), Fig. 18.

Valvulineria scrobiculata Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 70, Pl. 9, Fig. 5.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 85, Pl. 14, Figs. 32, 33.

This species was described from the middle Eocene of northern Africa, a region which has numerous species in common with the southern United States. It has been recorded from the Wilcox Eocene, Tuscahoma sand, one mile N. of Ozark, Alabama, and from the Bashi formation at Woods Bluff, Alabama. It is common in the Bashi material from near Yellow Bluff, Alabama.

Valvulineria wilcoxensis Cushman and Ponton (Pl. 1, Figs. 36, 37).

Valvulineria wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 70, Pl. 9, Fig. 6.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 85, Pl. 15, Figs. 1, 2.

This species occurs with the preceding one near Ozark and at Woods Bluff, Alabama. It occurs in typical form in the Bashi material from near Yellow Bluff, and both species should make good markers for this part of the Wilcox Eocene.

Genus EPONIDES Montfort, 1808.

Eponides lotus (Schwager) (Pl. 2, Figs. 5, 6).

Pulvinulina lota Schwager, Palaeontographica, Vol. 30, 1883, Pal. Theil, p. 132, Pl. 28(5), Fig. 9.

Eponides lotus Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 71, Pl. 9, Fig. 8.—Glaessner, Problems of Paleontology, Moscow Univ., Vols. 2-3, 1937, p. 379, Pl. 3, Fig. 26.—Bermudez, Mem. Soc. Cubana Hist. Nat., Vol. 12, 1938, p. 7.—Cushman and Garrett, Contr. Cushman Lab. Foram. Res., Vol. 15, 1939, p. 85, Pl. 15, Figs. 3-6.—Israelsky, Proc. 6th Pac. Sci. Congress, 1939, p. 578, Pl. 5, Figs. 1-4; Pl. 6, Fig. 1.—Cushman and Todd, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 40, Pl. 7, Figs. 13, 14.—Thalmann, Stanford Univ. Publ., Univ. Ser., Geol. Sci., Vol. 3, No. 1, 1942, p. 13 (list).

This species is now widely recorded from the Eocene of northern Africa, the Caucasus, Cuba, and the East Indies. It occurs in the Wilcox Eocene, Tuscahoma sand, near Ozark, Alabama, and from the Bashi formation at Woods Bluff, Alabama. It is common in the Bashi material from near Yellow Bluff. Specimens apparently identical occur in the Naheola formation of the Paleocene Midway group.

Genus SIPHONINA Reuss, 1850.

Siphonina wilcoxensis Cushman (Pl. 2, Figs. 3, 4).

Siphonina wilcoxensis Cushman, Proc. U. S. Nat. Mus., Vol. 72, Art. 20, 1927, p. 8, Pl. 2, Figs. 1-3.—Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 70, Pl. 9, Fig. 7.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 86, Pl. 15, Figs. 7-9.—Israelsky, Proc. 6th Pac. Sci. Congress, 1939, p. 578, Pl. 7, Fig. 8.—Toulmin, Journ. Pal., Vol. 15, 1941, p. 605, Pl. 81, Figs. 15, 16.

This species seems to be an excellent index fossil for the Wilcox Eocene, recorded from all the formations, and from the Eocene of California. It is common in the Bashi material from near Yellow Bluff.

Family CASSIDULINIDAE.

Genus PULVINULINELLA Cushman, 1926.

Pulvinulinella obtusa (Burrows and Holland) (Pl. 2, Figs. 7, 8).

Pulvinulina exigua H. B. Brady, var. *obtusa* Burrows and Holland, Proc. Geol. Assoc., Vol. 15, 1897, p. 49, Pl. 2, Fig. 25.—Plummer, Univ. Texas Bull. 2644, 1926 (1927), p. 151, Pl. 11, Fig. 2.

Pulvinulinella exigua (H. B. Brady), var. *obtusa* Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 71, Pl. 9, Fig. 9.—Jennings, Bull. Amer. Pal., Vol. 23, No. 78, 1936, p. 34, Pl. 4, Fig. 4.—Howe, Geol. Bull. 14, Louisiana Geol. Survey, 1939, p. 81, Pl. 11, Figs. 4-6.

Pulvinulinella obtusa Cushman and Garrett, l. c., Vol. 15, 1939, p. 27, Pl. 15, Figs. 12, 13.—Cushman and Renz, l. c., Vol. 18, 1942, p. 11, Pl. 2, Fig. 16.—Cushman and Todd, l. c., Vol. 18, 1942, p. 42, Pl. 7, Figs. 19, 20.

This species is widely distributed in the Midway, Wilcox, and Claiborne. It is rare in the Bashi material from near Yellow Bluff.

Family GLOBIGERINIDAE.

Genus GLOBIGERINA d'Orbigny, 1826.

Globigerina cf. compressa Plummer (Pl. 2, Figs. 9, 10).

Very small specimens with five chambers in the adult whorl were found in the material from near Yellow Bluff and may belong to this species which has been widely recorded from the Midway and Wilcox.

Globigerina triloculinoides Plummer (Pl. 2, Figs. 11, 12).

Globigerina triloculinoides Plummer, Univ. Texas Bull. 2644, 1926 (1927), p. 134, Pl. 8, Fig. 10.—Jennings, Bull. Amer. Pal., Vol. 23, No. 78, 1936, p. 35, Pl. 4, Fig. 10.—Glaessner, Problems of Paleontology, Moscow Univ., Vols. 2-3, 1937, p. 382, Pl. 4, Fig. 33.—Cushman, Contr. Cushman Lab. Foram. Res., Vol. 16, 1940, p. 72, Pl. 12, Fig. 15.—Toulmin, Journ. Pal., Vol. 15, 1941, p. 607, Pl. 82, Fig. 3.—Cushman and Todd, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 48, Pl. 8, Figs. 1, 2.—Thalmann, Stanford Univ. Publ., Univ. Ser., Geol. Sci., Vol. 3, No. 1, 1942, p. 13 (list).

This species is widely distributed in the Paleocene, Midway and lower Eocene Wilcox. Specimens from the Bashi near Yellow Bluff seem to be typical.

Globigerina cf. pseudo-bulloides Plummer (Pl. 2, Fig. 13).

A few specimens in the material from near Yellow Bluff may belong to this species.

Family GLOBOROTALIIDAE.

Genus GLOBOROTALIA Cushman, 1927.

Globorotalia wilcoxensis Cushman and Ponton (Pl. 2, Figs. 14, 15).

Globorotalia wilcoxensis Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 71, Pl. 9, Fig. 10.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 88, Pl. 15, Figs. 21, 22.

The records for this species are from the Wilcox Eocene, Tuscahoma sand, one mile N. of Ozark, Alabama, and from the Bashi formation at Woods Bluff, Alabama. It is frequent in the Bashi material from near Yellow Bluff, Alabama. Cole records it from the Midway Paleocene of Florida wells but the figure given is apparently not the same as the Wilcox species.

Globorotalia wilcoxensis Cushman and Ponton, var. acuta Toulmin (Pl. 2, Figs. 16, 17).

Globorotalia wilcoxensis Cushman and Ponton, var. *acuta* Toulmin, Journ. Pal., Vol. 15, 1941, p. 608, Pl. 82, Figs. 6-8.—Cushman and Renz, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 12, Pl. 3, Fig. 2.

The types of this variety are from the Salt Mountain limestone of the Wilcox Eocene of Alabama. It occurs also in the Paleocene of Trinidad. A few specimens occurred in the Bashi material from near Yellow Bluff.

Family ANOMALINIDAE.

Genus ANOMALINA d'Orbigny, 1826.

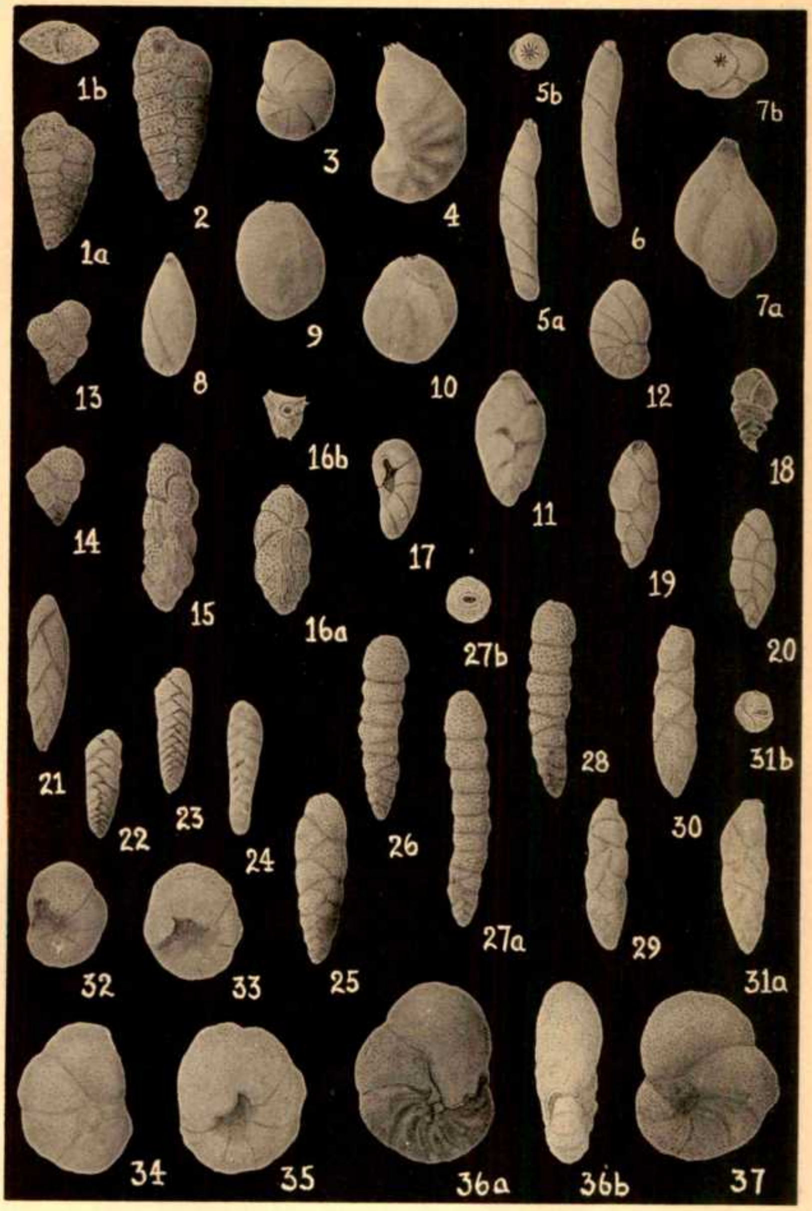
Anomalina umbonifera (Schwager) (Pl. 2, Figs. 18, 19).

Discorbina umbonifera Schwager, Palaeontographica, Vol. 30, 1883, Pal. Theil, p. 126, Pl. 27(4), Fig. 14.

EXPLANATION OF PLATE I.

(All figures X50.)

Figs. 1, 2. *Spiroplectammina wilcoxensis* Cushman and Ponton. 1a, side view; *b*, apertural view.
Fig. 3. *Robulus* sp.
Fig. 4. *Marginulina* sp.
Figs. 5, 6. *Dentalina wilcoxensis* Cushman, n. sp. 5, Holotype, *a*, side view; b, apertural view. 6, Paratype.
Fig. 7. *Guttulina problema* d'Orbigny, var. *arcuata* Cushman, n. var. *a*, side view; *b*, apertural view.
Fig. 8. *Guttulina wilcoxensis* Cushman and Ponton.
Figs. 9, 10. *Globulina gibba* d'Orbigny.
Fig. 11. *Polymorphina* sp.
Fig. 12. *Nonionella wilcoxensis* Cushman and Ponton.
Figs. 13, 14. *Gümbelina wilcoxensis* Cushman and Ponton.
Figs. 15, 16. *Pseudouvigerina naheolensis* Cushman and Todd. 16*a*, side view; *b*, apertural view.
Fig. 17. *Robertina wilcoxensis* Cushman and Ponton.
Fig. 18. *Eouvigerina excavata* Cushman.
Figs. 19, 20. *Virgulina wilcoxensis* Cushman and Ponton.
Fig. 21. *Virgulina* cf. *dibollensis* Cushman and Applin.
Figs. 22, 23. *Bolivina* cf. *midwayensis* Cushman.
Fig. 24. *Loxostomum wilcoxense* Cushman and Ponton.
Fig. 25. *Loxostomum* sp.
Figs. 26-28. *Bifarina tombigbeensis* Hadley. 27*a*, side view; *b*, apertural view.
Figs. 29-31. *Uvigerina alabamensis* Cushman and Garrett. 31*a*, side view; *b*, apertural view.
Figs. 32-35. *Lamarckina wilcoxensis* Cushman. 32, 33, 35, ventral views; 34, dorsal view.
Figs. 36, 37. *Valvulineria wilcoxensis* Cushman and Ponton. 36*a*, ventral view; *b*, peripheral view; 37, dorsal view.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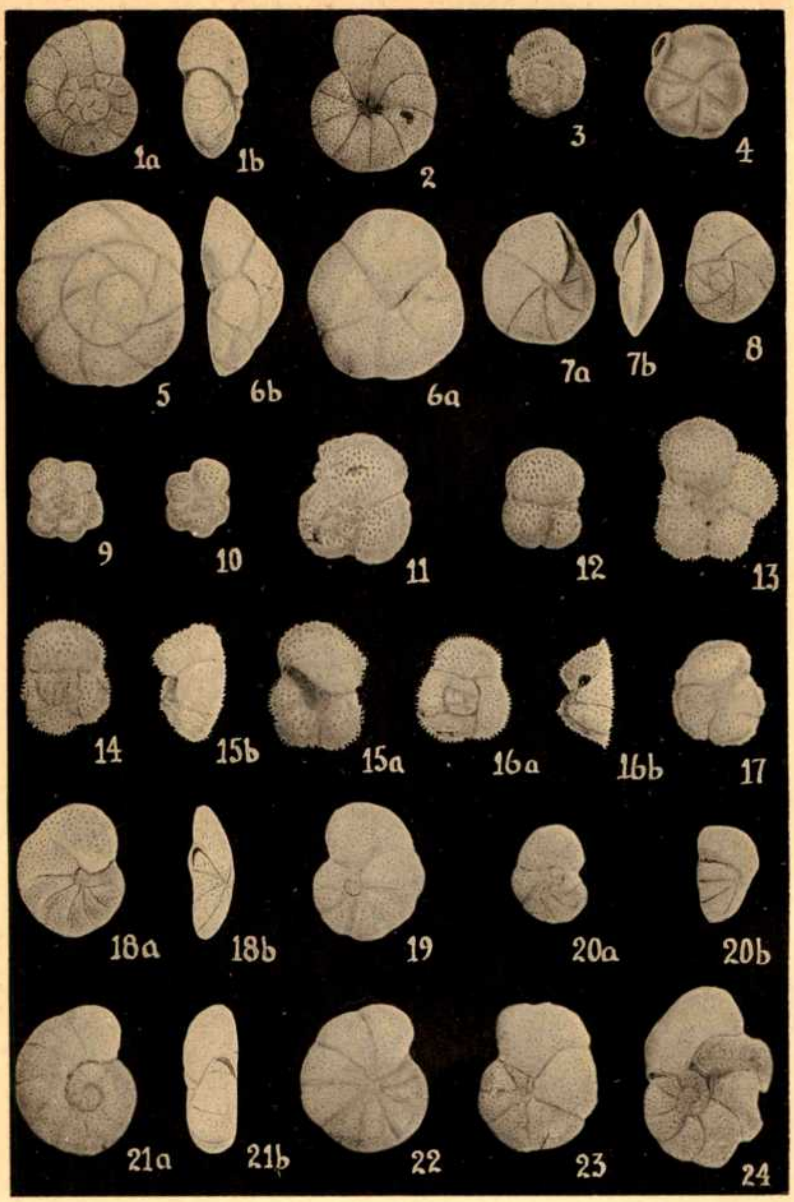
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EXPLANATION OF PLATE 2.

(All figures X50.)

Figs. 1, 2. *Valvulineria scrobiculata* (Schwager). 1*a*, dorsal view; *b*, peripheral view; 2, ventral view.

Figs. 3, 4. *Siphonina wilcoxensis* Cushman. 3, dorsal view; 4, ventral view.

Figs. 5, 6. *Eponides lotus* (Schwager). 5, dorsal view; 6*a*, ventral view; *b*, peripheral view.

Figs. 7, 8. *Pulvinulinella obtusa* (Burrows and Holland). 7*a*, ventral view; *b*, peripheral view; 8, dorsal view.

Figs. 9, 10. *Globigerina* cf. *compressa* Plummer. 9, dorsal view; 10, ventral view.

Figs. 11, 12. *Globigerina triloculinoides* Plummer. 11, dorsal view; 12, ventral view.

Fig. 13. *Globigerina* cf. *pseudo-bulloides* Plummer. Ventral view.

Figs. 14, 15. *Globorotalia wilcoxensis* Cushman and Ponton. 14, dorsal view; 15*a*, ventral view; *b*, peripheral view.

Figs. 16, 17. *Globorotalia wilcoxensis* Cushman and Ponton, var. *acuta* Toulmin. 16*a*, dorsal view; *b*, peripheral view; 17, ventral view.

Figs. 18, 19. *Anomalina umbonifera* (Schwager). 18*a*, dorsal view; *b*, peripheral view; 19, ventral view.

Fig. 20. *Cibicides blanpiedi* Toulmin. *a*, dorsal view; *b*, peripheral view.

Figs. 21, 22. *Cibicides howelli* Toulmin. 21*a*, dorsal view; *b*, peripheral view; 22, ventral view.

Figs. 23, 24. *Cibicides praecursorius* (Schwager). 23, ventral view; 24, dorsal view.

Anomalina umbonifera Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 72, Pl. 9, Fig. 11.

The types of this species are from the middle Eocene of northern Africa. It occurs in the Wilcox Eocene, Tuscahoma sand, from one mile N. of Ozark, Alabama. Similar specimens were found in the Bashi material from near Yellow Bluff, Alabama.

Genus CIBICIDES Montfort, 1808.

Cibicides praecursorius (Schwager) (Pl. 2, Figs. 23, 24).

Discorbina praecursoria Schwager, Palaeontographica, Vol. 30, 1883, Pal. Theil, p. 125, Pl. 27(4), Fig. 12; Pl. 29(6), Fig. 16.
Cibicides praecursorius Cushman and Ponton, Contr. Cushman Lab. Foram. Res., Vol. 8, 1932, p. 72, Pl. 9, Fig. 14.—Cushman and Garrett, l. c., Vol. 15, 1939, p. 88.—Toulmin, Journ. Pal., Vol. 15, 1941, p. 610, Pl. 82, Figs. 19-21.—Cushman and Renz, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 13, Pl. 3, Fig. 9.—Cushman and Todd, l. c., Vol. 18, 1942, p. 45, Pl. 8, Figs. 17-20.

This species described from the middle Eocene of northern Africa occurs in the Midway Paleocene and Wilcox Eocene of the southeastern United States. Specimens are fairly common in the Bashi material from near Yellow Bluff, Alabama.

Cibicides blanpiedi Toulmin (Pl. 2, Fig. 20).

Cibicides blanpiedi Toulmin, Journ. Pal., Vol. 15, 1941, p. 609, Pl. 82, Figs. 11-13.—Cushman and Todd, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 46, Pl. 8, Figs. 13-15.

The records for this species include the Salt Mountain limestone and the Nanafalia formation of the Wilcox group and the Naheola formation of the Midway group. A single specimen in the Bashi material from near Yellow Bluff, Alabama, seems to belong to this species.

Cibicides howelli Toulmin (Pl. 2, Figs. 21, 22).

Cibicides cf. *pseudoungerianus* Cushman and Garrett, Contr. Cushman Lab. Foram. Res., Vol. 15, 1939, p. 88, Pl. 15, Figs. 25, 26.
Cibicides howelli Toulmin, Journ. Pal., Vol. 15, 1941, p. 609, Pl. 82, Figs. 16-18.—Cushman and Renz, Contr. Cushman Lab. Foram. Res., Vol. 18, 1942, p. 13, Pl. 3, Fig. 10.

This species is recorded from the several formations of the Wilcox Eocene and from the Paleocene of Trinidad. There is a considerable amount of variation in our specimens from the Bashi formation near Yellow Bluff, Alabama, but they seem to form one series.

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THE SEDIMENTS OF FOUR WOODLAND LAKES, VILAS COUNTY, WISCONSIN.

Part I.

W. H. TWENHOFEL, V. E. McKELVEY, S. A. CARTER, and HENRY NELSON.

ABSTRACT. The sediments of four lakes in the Northern State Forest of northern Wisconsin, Allequash, Little John, Muskellunge, and Nebish, are described. The lakes are surrounded by forest and no parts of the surrounding lands have been cultivated. The lake basins are pits in outwash and the shores are largely composed of sands. Shores are generally low and wave attack upon them is weak, and thus contribution of sediments from the shores is small. Sampling was done of the sediments on the present bottom and, by means of core samplers, of the sediments which have accumulated since the origin of the lakes. The sampling shows the slow rate of accumulation of the sediments.

INTRODUCTION.

THE four lakes of which the sediments are considered in this paper are Nebish, Little John, Muskellunge, and Allequash. All are in the same general region of Vilas County, Wisconsin, and in the Northern State Forest. All are woodland lakes and all lie in basins in glacial outwash deposits which are mainly quartz sands and silts. Some gravels are usually interbedded with the sands and silts. Bed rock is not known to be present around the borders of any of the lakes, but there may be an occasional large erratic. The lakes are not large. The map of Fig. 1 shows the relations of the lakes to each other and to the large Trout Lake.

Allequash and Little John lakes have a common outlet into Trout Lake. Muskellunge drains through swamp into Allequash Lake. Nebish Lake has no outlet in the form of a stream.

Muskellunge is the largest of the four lakes and has an area of around 900 acres. About 400 acres are covered by Allequash Lake, and Nebish and Little John Lakes cover about 100 acres each.

Each lake is surrounded by forest, mostly second growth, on nearly all parts of its shores. The waters are soft in each and none has any significant indraining stream except Allequash and this is not very large. The lakes were selected for

study because of their interwoodland positions and their close relations to each other.

The wet sediments of each of the lakes on bottoms below the depth of about three meters consist largely of materials of organic origin and this is also generally true after the sediments have been dried. Colors of wet sediments on gross appearance range from dark-greenish to dark-brownish black. Under the microscope the color of the organic-rich sediments in thin layers is a pale greenish yellow and the most abun-

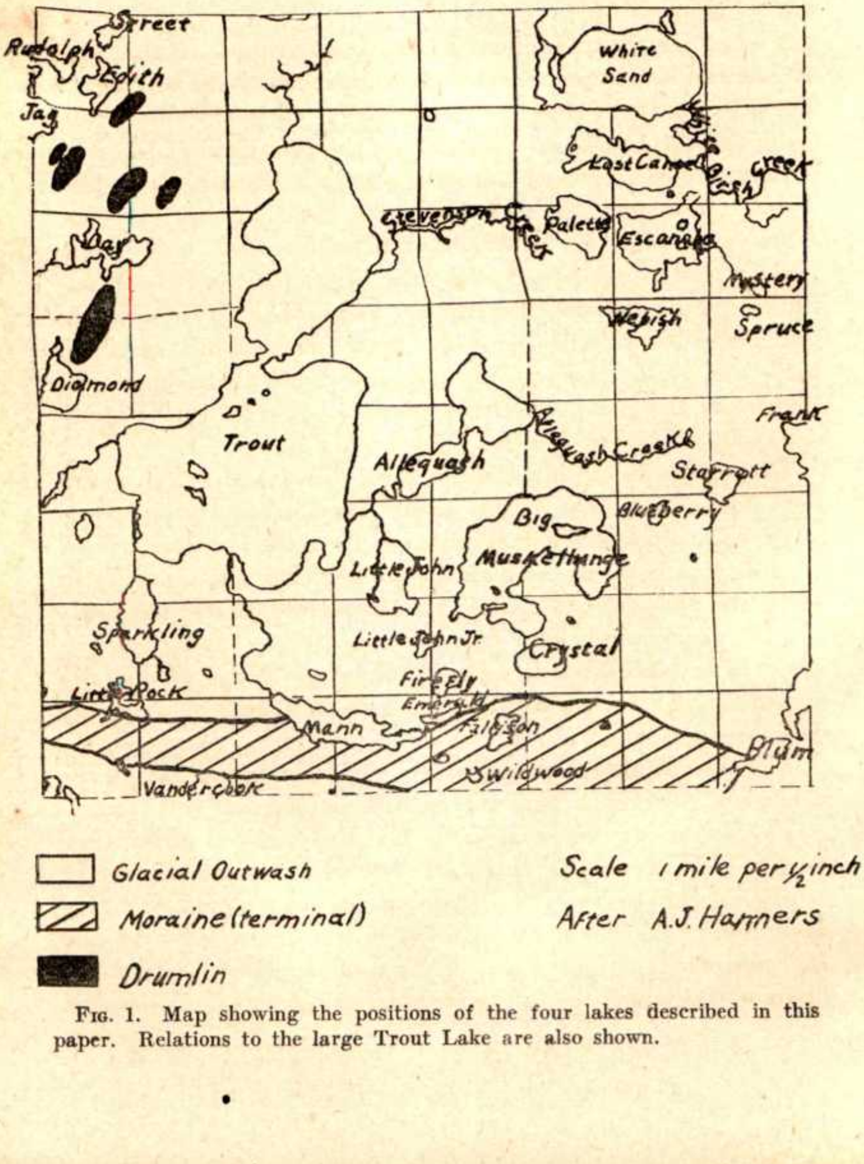

FIG. 1. Map showing the positions of the four lakes described in this paper. Relations to the large Trout Lake are also shown.

dant substance is a pale-greenish yellow gel in the form of irregularly globular units about 2 mm. in diameter. Enmeshed in the gel are sponge spicules, diatom tests, conifer needles, pollen grains, pieces of leaves, fragments of stems and bark, minute fragments of organic matter of indeterminate origin, and detrital particles of inorganic origin. Drying of these sediments produces a tough, somewhat rubbery, black to gray solid which breaks with difficulty, absorbs water slowly, does not fall apart when placed in water, and in many cases will float on water and may require several days before it becomes water-logged.

The writers have applied the term of "sludge" to this type of sediments. Other authors have used the term of "ooze." The latter usage is clearly objectionable. Objections have been made against the use of "sludge" on the ground that the term is preoccupied in connection with sewage. Deevey states that "ooze," "sludge," and the European term of "gyttja" are synonymous and he urges adoption of the last term. The authors are in agreement with this suggestion and the European term is used in this paper. Deposits of gyttja in the four lakes considered generally begin at a depth of about three meters, or ten feet, the limiting depth depending upon the size of the lake. There are places where this type of sediment extends to the shore.

The sediments on bottoms less than three meters deep in the four lakes considered in this paper are dominantly composed of gravels, sands and silts with sands the most common. Some organic materials are ordinarily present but the quantity is small and the transition zone from inorganic clastic sediments to gyttja is a narrow one.

Cores were acquired in some of the lakes. None showed any stratification. It may be that some stratification would develop on consolidation.

The lakes were not all studied in the same way either in the field or laboratory. This was conditioned by field relations.

The writers are indebted to the Graduate School of the University of Wisconsin for financial support of the studies of lake sediments, for without that support the work could not have been done. They are also indebted to Dr. Chancey Juday and the personnel of the Trout Lake Limnological Station for financial assistance, use of apparatus, and general coöperation.

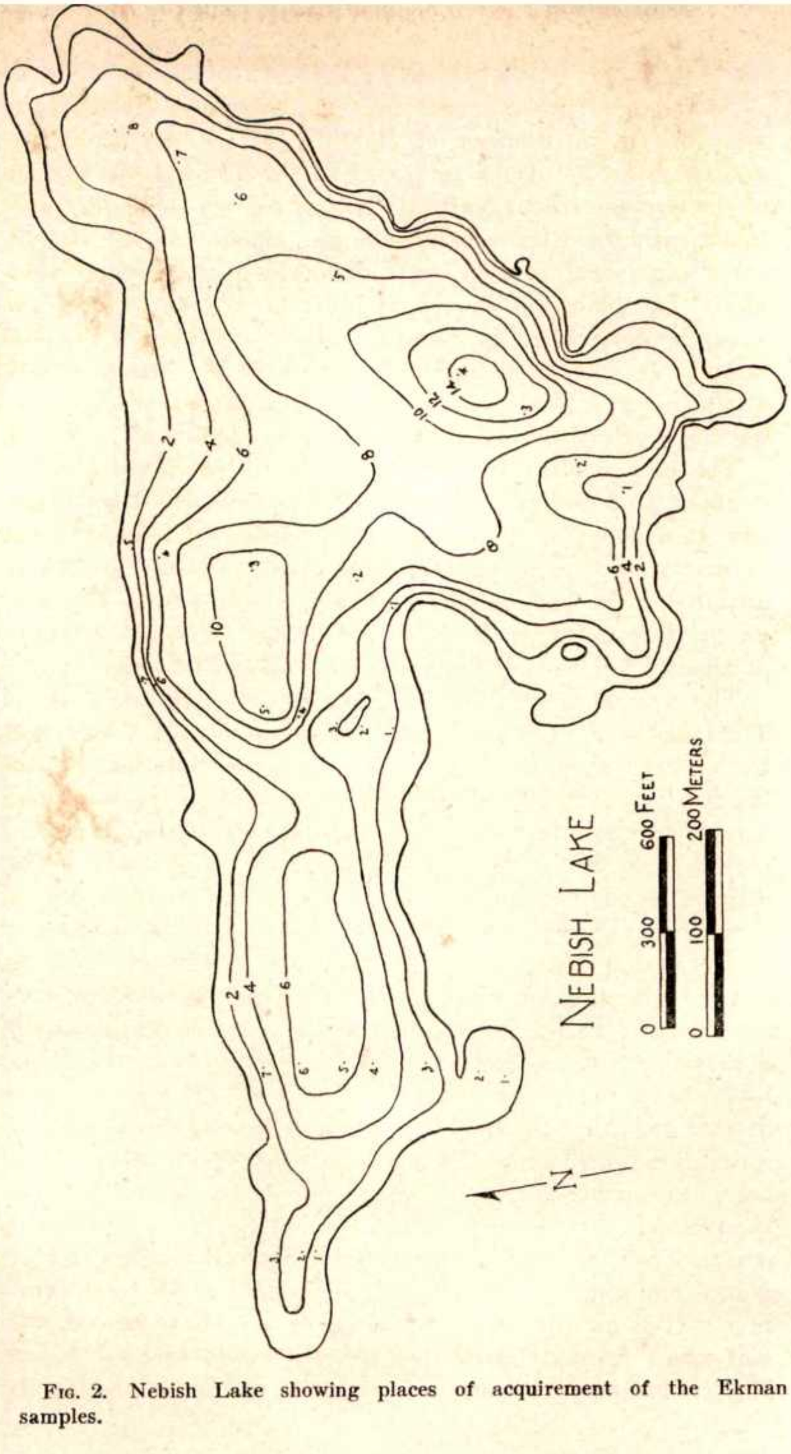

FIG. 2. Nebish Lake showing places of acquirement of the Ekman samples.

NEBISH LAKE AND ITS SEDIMENTS.

Sampling of the sediments over the bottom of Nebish Lake was done in the summer of 1939 by Mr. V. E. McKelvey assisted by some of the personnel at the Trout Lake Station of the Geological and Natural History Survey. Samples were taken with the Ekman sample to the number of 70, and six cores were acquired with the Jenkin and Mortimer core sampler. The places of acquirement of the Ekman samples are shown by figures in Fig. 2 and the places of taking of the core samples are indicated by the letters A to F. Samples were also acquired with a spud sampler for the purpose of determining the depth of the sediments. These are indicated in Fig. 3.

The maximum depth of the lake is on the southeast where it is about 15.2 meters (50 feet). It was formerly deeper than now as a minimum of at least three meters of sediments has accumulated at the places where most of the cores were acquired. The bottom is irregular as shown by the contours on the maps of Figs. 2 and 3. The shore line has a length of about 2.5 miles and the area of the lake is 95 acres.

The drainage from Nebish Lake is extremely interesting. The lake seems to lie on a seal over sands in such a way that the level of the water, at least at times, can be maintained above the local water table. There is a depression on the southwest margin just east of the west end of which the bottom is two to three meters below the level of the water in the lake. The depression was either empty or nearly empty of water during the summers of 1940 and 1941. The deepest part of the depression is perhaps 50 meters from the shore of the lake and the top of the separating ridge is four to five meters wide. A shallow ditch, which was not over a third of a meter deep, was cut across this ridge in 1940 and water rapidly flowed from the lake into the depression where it disappeared. It was estimated at that time that the quantity of water flowing from the lake into this depression was of the order of 150,000 gallons per day. Ice push or the washing of waves closed the channel between the summers of 1940 and 1941. The bottom of the depression is thinly covered with fine-grained sediments through which an animal had dug numerous holes and brought sands to the surface. It is possible that this digging may have broken the seal which formerly permitted the depression to hold water. That it formerly held water to the level of that in the lake is

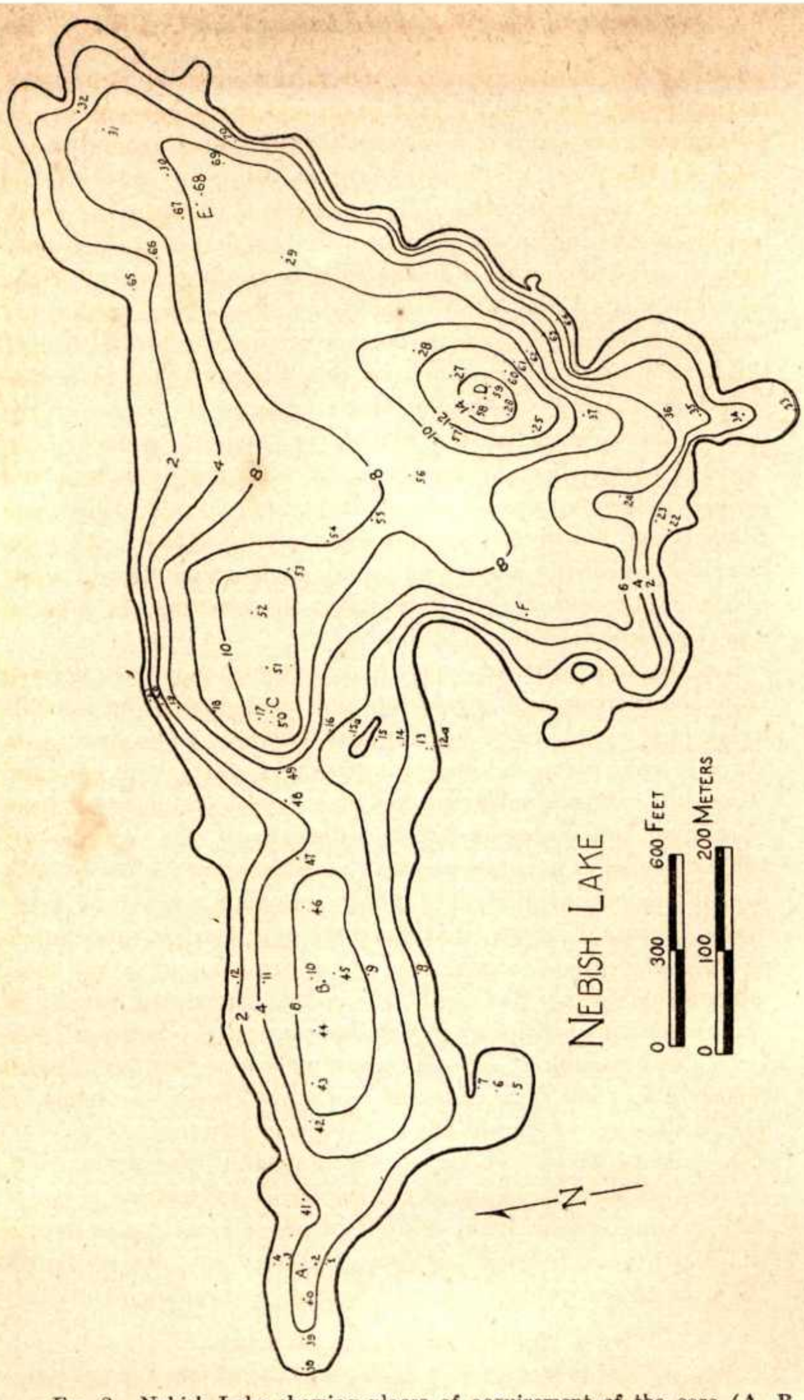

FIG. 3. Nebish Lake showing places of acquirement of the core (A. B. etc.) and spud samples.

shown by the absence of trees and shrubs over the depression to that level. As both the lake basin and the depression are in porous outwash sands it is obvious that the local ground water table at the times of observation was below the level of the bottom of the depression. It is suggested that in the early history of the region the ground water table was much higher than at present and then coincided with the water level of the lake which may also have been higher than now. Sediments were then deposited over the bottom of the lake and also over the bottom of the depression and this ultimately led to a considerable seal over the sands which underlie the basin of the lake. This sealing of the bottom is thought to have been brought about through deposition of silt by melt waters and probably began immediately with retreat of the Wisconsin Glacier, and before the establishment of vegetation. At some later date, perhaps only recently, the local ground water table fell below the water level of the lake, thus leaving the lake on a perched water table.

The organic sediments deposited in Nebish Lake are derived from the surrounding vegetation and from plants and animals living in the lake. The small brooks which at times drain into the lake may bring in small quantities of clastic and colloidal sediments. Some inorganic sediments may be derived from erosion of the shores and some sediments of this origin must fall from the atmosphere. Most of the sediments in the lake are of organic origin. The plant materials consist of fragments of leaves, stems, and bark, conifer needles, and pollen grains, all derived from plants living around and in the lake, and diatom tests. Sediments of animal origin may consist of sponge spicules, shells of invertebrates, and the bones of fish, frogs, and tadpoles. The lake has numerous fish, but shelled invertebrates are few. No shells of invertebrates or bones of vertebrates were found in any of the sediments.

Sediments which are largely of inorganic derivation cover the shallow bottom adjacent to the shores and extend outward with gradually increasing content of organic matter to depths which are usually less than three meters. At greater depths the sediments are very largely composed of organic matter.

THE WATERS OF NEBISH LAKE.

The waters of Nebish Lake have a brown shade due to colloidal organic matter in suspension. The pH ranges from about

6.8 in the top waters to 6.0 on the bottom of the deep hole on the southwest end. There is a gradual decrease of the pH with depth. The quantity of material in solution in the waters of the lake is small and for silica it ranges from about 0.1 part per million in the surface waters to 0.6 part per million at the depth of 13.5 meters and 0.7 part per million in the deepest part. On August 23, 1932, the silica in solution ranged from 0.4 part per million in the surface waters to 1.4 parts per million at the depth of 14 meters. Calcium ranged from 2.25 parts per million in the surface waters to 3.5 parts per million at the depth of 12 meters (40 feet). Magnesium ranged from nothing in the surface waters to 0.3 parts per million at the depth of 12 meters (40 feet). Ferrous and ferric iron on August 4, 1934, ranged from nothing in the surface waters to about 1.6 and 0.1 parts per million respectively at the depth of 14 meters. Total elemental iron on August 23, 1932, ranged from 0.06 parts per million in the surface waters to 1.0 parts per million at the depth of 14 meters. On the same date elemental manganese ranged in these depths from 0.01 to 0.2 part per million. Oxygen and carbon dioxide on August 1, 1921, ranged respectively from 8.1 and 1.6 parts per million in the surface waters to 0.2 and 21.6 parts per million at the depth of 14 meters (Juday, Birge and Meloche).

These figures show that the waters of Nebish Lake contain little inorganic matter in solution. This is some little contrast to the waters of Allequash, Muskellunge, and Little John lakes in which the quantities of dissolved salts are greater. The waters of Nebish Lake seem to be oligotrophic.

PHYSICAL COMPOSITION OF THE SEDIMENTS OF NEBISH LAKE.

The sediments over the bottom of Nebish Lake below the depth of about three meters are rich in organic materials and belong to the variety of organic-rich sediments known as gyttja. These sediments are dark-greenish to dark-brownish black when wet and gray to black when dry. Mechanical analyses of these sediments must be made before they are dried. If the sediments are dried, it is essentially impossible again to separate them into the original particles. Under the microscope the most abundant substance in the gyttja is a pale greenish yellow gel.

Some mechanical analyses were made of all the samples col-

lected, but it is thought that the results are essentially meaningless from the point of view of sedimentation. The detrital materials are mingled with sponge spicules, diatom tests, and pieces of leaves, stems and bark. All particles are enmeshed in the pale greenish yellow gel from which it has been found impossible completely to separate them. There is no reason to believe that the particles are of the same dimensions as when they settled to the bottom. It is possible that some are larger, others smaller. They were probably flocculated at the time of settling. Mechanical analyses were made of sediments from the shallow water to depths not exceeding three meters. The map shows the positions of these samples and their physical constitution is shown in Table 1. It is interesting to note the vast differences in physical composition of sediments from the same depth. Thus, sample 8, with no particles as large as 4 mm. should be compared with sample 13, where the largest percentage is larger than 4 mm. Samples 1 and 66 show a small decrease in dimension with slight increase in depth. Samples 7, 12, 13, 24, and 38 contain many particles larger than 4 mm. in diameter. It will be noted that samples 1, 7, 8, 12, 15a, and 65 have more than half the sediments in the range from ⅛ to 1 mm. in diameter, whereas samples 13, 24, and 38, all in very shallow water except 24, have the maximum quantity in dimensions of 4 or more mm. in diameter. Samples over the deep parts of the lake, that is below three meters, have the detrital particles dominantly around ⅛ mm. or less in diameter. Analyses show larger diameters but these largely arise from fragments of vegetable matter.

TABLE 1. Mechanical Analyses of Shallow Water Sediments.

Grade Dimensions in mm.

Sample	Water Depth	4	2	1	½	¼	⅛	1/16	1/16
1	2.4 m.	0.00%	3.61%	4.78%	16.10%	46.85%	23.92%	4.52%	0.00%
7	1	25.15	3.29	12.14	37.10	14.90	2.66	0.00	0.00
8	1	0.00	3.51	2.69	40.85	29.60	9.18	3.36	0.00
12	1.5	29.80	2.65	5.80	17.10	33.95	9.54	0.95	0.00
13	1	45.30	1.08	1.94	5.76	26.50	11.78	2.90	0.79
15a	1	2.59	2.99	4.96	15.40	46.99	21.39	4.39	1.35
24	3	55.20	2.25	3.24	11.07	23.75	4.48	0.39	0.00
38	1	38.23	2.79	2.90	7.05	23.60	12.72	2.68	0.00
65	1	3.58	0.33	1.37	8.24	52.30	30.60	3.86	0.00
66	3.6	0.00	0.00	1.95	8.54	43.75	40.30	5.43	0.00

The figures of the table do not state the facts accurately, as most of the samples contain small quantities of pieces of leaves, stems, bark, and conifer needles and these shift the frequencies to the larger dimensions and thus make the sediments seem coarser than they really are. It is also probable that some of the very fine materials are adherent to the larger because of the gel which may be present in some samples.

The samples of the six cores are not unlike the materials of the bottom at the places where they were taken except in the one case where the materials below the organic sediments were penetrated. Descriptions of the core samples together with the Ekman sample of the place of taking are as follows.

Core A. (Water 2.7 meters deep.) The Ekman sample is greenish black in gross appearance, but the composing materials are largely a pale greenish-yellow gel which contains many pollen grains, a few sponge spicules, some diatoms, and small particles of quartz and other minerals. The number of sponge spicules is about equal to that of the diatoms and neither seems to be numerous. The diatoms are fusiform, slender, and some are constricted slightly between the middle and the ends. The core is represented by eight samples which extend through a thickness of sediments of ten feet, or a little less than three meters.

Core B. (Water seven meters deep.) The Ekman sample is greenish-black and is largely composed of pale greenish-yellow gel which contains many pollen grains, a few diatoms and sponge spicules, the latter more common, and small angular particles of clear quartz.

The core samples were dry when studied and consisted of dark gray, very hard and tough materials. Some samples were covered with small, light-colored, fibrous crystals. The samples floated on water, did not readily wet, absorbed water very slowly and showed no indication of falling apart after soaking for 24 hours. The core is ten feet long (about three meters), and is represented by ten samples.

Core C. (Water 11 meters deep.) The Ekman sample has a greenish-black color, but is largely composed of the pale greenish-yellow gel in which are many fusiform diatoms. The dry core samples are black, hard, and tough. The sediments at the depth of three meters beneath the bottom contain numerous sponge spicules. All samples contain many pollen grains, but diatoms do not seem to be abundant. Some samples contain

small, white-colored spherulites with fibrous structure. The core is about three meters long and is represented by ten samples.

Core D. (Water about 15 meters deep.) The Ekman sample is greenish-black in gross color, but is composed of pale greenish-yellow gel in which are enmeshed many pollen grains, some sponge spicules and fusiform diatoms, and small angular particles of quartz. The wet core sample from the depth of two meters below the bottom of the lake had a strong odor of hydrogen sulphide which was probably produced from the decay of organic matter. The color of the samples from the core is dark gray to black, but the sediments are largely composed of pale greenish-yellow gel which contains many pollen grains, plant fibers, quite common but not abundant sponge spicules, diatom tests, and small angular particles of quartz. The core is nine feet (a little less than three meters) long, with a sample for each foot.

Core E. (Water about six meters deep.) The Ekman sample consists of fine sand with which there is not a great deal of organic matter. The top foot of the core is black, and contains many pollen grains, common diatoms, and more common sponge spicules. The second foot consists of silt containing some organic matter. This sample represents two layers of which the upper is a black and tough clay with much organic matter, and the other is composed of friable, dark gray silt. The third foot is sand and silt with little organic matter. This core is three feet long (a little less than one meter).

Core F. (Water about six meters deep.) This is the longest core obtained. The sediments were penetrated to the depth of about 4.5 meters. They consist of pale greenish-yellow gel with enmeshed pollen grains, fragments of plants, sponge spicules, diatom tests, and small angular particles of quartz. The gross color is greenish-black.

WATER CONTENT OF THE SEDIMENTS.

The sediments were analyzed for water immediately on arrival in the laboratory. Not all samples were analyzed and few determinations were made of the samples taken with the Ekman dredge. The water contents of cores A to F together with the Ekman samples taken in connection with the cores are given in Table 2. Each sample represents one foot or about a third of a meter.

TABLE 2. Water Contents of Sediments of Cores B, C, D, and F.

Sample No.	Core A	Core B	Core C	Core D	Core F
Ekman		83.4%			96.2%
1 ft.	88.3%	90.7	92.7%	....	....
2		93.4			94.6
3	95.1	94.0	93.6	91.5%	93.7
4		92.7			92.9
5	83.4	92.3	87.9	81.6	92.1
6		86.6			92.3
7	86.1	86.4	84.8	87.8	93.3
8		82.2			91.5
9		87.2	85.3	86.8	86.0
10		84.2			83.0
11					85.4
12					85.6
13					85.3
14					79.3
15					87.8

The average water content of Core F is 87.6 per cent. A gradual decrease in water content takes place with depth but the average percentage is present at the greatest depth attained. If the water were expelled from the sediments and they were compacted, the 4.5 meter column of Core F would be reduced to about 0.6 meter of sediments. However, it is probable that not all of the water could be expelled and perhaps the thickness of sediments remaining might be equal to about one meter.

Except for Core E, the bottom of the sediments deposited since the Ice Age was not reached in any of the core sampling, hence the actual maximum depth of sediments in Nebish Lake is not known. Sediments in lakes at no great distance show a range from about three meters in Crystal Lake to 12.77 meters (42 feet) in Lake Allequash. It is assumed that the maximum depth in Nebish Lake is somewhere between these extremes with the probability that it is nearer the lower extreme than the upper.

SPUD SAMPLING.

The sediments over the bottom of the lake were studied by means of a spud sampler. The places of sampling are shown on the map of Fig. 3. Results are given in the paragraphs which follow. If sand is present in the samples, it is so stated. If not so stated, it was not observed.

Range No. 1.

1. Water 1.7 meters deep.
   0–0.8 meter. Greenish-brown gyttja with plant fiber in the lower part.
   0.84–1.17 meters. Gray sand and silt with organic matter, sand, pinkish gray in basal inch.
2. Water 8 meters deep.
   0–2.80 meters. Greenish-gray gyttja with plant fibers and fragments of wood in basal third. Becomes slightly pinkish in color near base.
3. Water 1.5 meters deep.
   0–0.18 meter. No sample.
   0.18–0.48 meter. Gray sand with woody fragments and other organic matter. Sand pinkish-gray without organic matter in lowest 7 cm.

Range No. 2.

1. Water 1.8 meters deep.
   0–2.87 meters. Greenish-gray gyttja with plant fibers in lower half.
2. Water 1.8 meters deep.
   0–0.42 meter. Greenish-gray gyttja.
   0.42–1.28 meters. Brown gyttja with plant fragments and sand and gravel, rests on pinkish-gray sand and gravel without organic matter.
3. Water 2.2 meters deep.
   Gravel penetrated at 15 cm. Thin gyttja above.
4. Water 5.7 meters deep.
   0–1.41 meters. Greenish-brown gyttja with plant fiber, rests on pinkish-gray sand and silt without organic matter.
5. Water 7 meters deep.
   0–4.95 meters. Greenish-gray gyttja without plant fiber.
6. Water 7.7 meters deep.
   0–8.96 meters. Greenish gray gyttja.
7. Water 2.7 meters deep.
   0–1.11 meters. Greenish-gray and greenish-brown gyttja with sand and plant fiber in lower part.
   1.11–1.28 meters. Brownish-gray sand and pebbles with a little organic matter and pinkish gray sand without organic matter at the base.

Range No. 8.

1. Water 2 meters deep.
   0–0.7 meter. Greenish-brown gyttja with plant fiber resting on grayish-brown sand with little organic matter.
2. Water 5.15 meters deep.
   0–2.7 meters. Greenish-brown gyttja with plant fiber in lower half.

3. Water 8.5 meters deep.
   0–8.68 meters. Greenish-brown gyttja without plant fiber.
4. Water 7 meters deep.
   0–4.62 meters. Greenish-brown gyttja.
5. Water 3.3 meters deep.
   0–1.05 meters. Greenish-brown gyttja with woody fragments and sand in lower half resting on pinkish-gray sand without organic matter.

Range No. 4.

1. Water 2 meters deep.
   0–2.04 meters. Greenish-brown gyttja with plant fiber and wood, sand and gravel in lower half.
2. Water 1.8 meters deep.
   0–0.42 meter. Sandy gyttja or muck, spud struck gravel.
3. Water 2.3 meters deep.
   0–0.12 meter. Dark gyttja on gray sand and silt.
4. Water 7.5 meters deep.
   0–2 meters. Greenish-dark gray gyttja, sandy in basal inch and resting on light brown sand with no organic matter.
5. Water 10.8 meters deep.
   0–2.83 meters. Greenish-dark gray gyttja.
6. Water 6.5 meters deep
   0–0.68 meter. Gray gyttja with a little sand.
7. Water 8 meters deep.
   0–0.80 meter. Brownish-gray sand with organic matter at top and pinkish-gray sand without organic matter at base.

Range No. 5.

1. Water 2.7 meters deep.
   0–0.09 meter. Greenish-brown gyttja with some sand and plant fiber on light-brown sand and granules, no organic matter.
2. Water 7.6 meters deep.
   0–1.51 meters. Greenish-brown gyttja with plant fiber in the lowest six inches, rests on bluish-gray clay.
3. Water 10.25 meters deep.
   0–3.72 meters. Greenish-brown gyttja with plant fiber in basal part, rests on brown sand and silt with a little organic matter.
4. Water 7 meters deep.
   0–1.92 meters. Greenish-brown gyttja on pinkish-brown sand and silt without organic matter.
5. Water 4 meters deep.
   0–0.12 meter. Grayish-brown sand and silt with a little organic matter.

Range No. 6.

1. Water 2.8 meters deep.
   0–0.69 meter. Brown sand with organic matter above brown sand without organic matter.
2. Water 5 meters deep.
   0–2.22 meters. Greenish-brown gyttja with plant fiber in lower part, rests on grayish-blue clay with a little organic matter in top part.
3. Water 8.8 meters deep.
   0–2.5 meters. Grayish-brown gyttja on brown sand with organic matter.
4. Water 14.8 meters deep.
   0–8 meters. Greenish-brown gyttja.
5. Water 10.9 meters deep.
   0–2.9 meters. Greenish-brown gyttja.
6. Water 6.7 meters deep.
   0–1.85 meters. Greenish-brown gyttja on grayish-brown sand with organic matter above pinkish-brown sand without organic matter.
7. Water 6 meters deep.
   0–1.88 meters. Greenish-brown gyttja with plant matter in bottom foot and some sand at base, rests on pinkish-brown sand without organic matter.
8. Water 5.5 meters deep.
   0–2.64 meters. Greenish-brown gyttja with plant fiber in lower part and some sand in bottom foot.

The spud samples throw a little more light on the depth of the sediments than is given by the core samples. It seems obvious that over much of the bottom the thickness of the sediments rarely exceeds four meters and that in many places it is less than half that figure. It is only in the very deep places that the thickness is greater than four meters.

CHEMICAL COMPOSITION OF THE SEDIMENTS.

The organic contents of the sediments of Cores B, E and F, based on loss on ignition, were determined by Mr. McKelvey and are given in Table 3. It is certain that the figures are not quite correct as some of the loss is due to water in diatom tests, sponge spicules and in the small quantity of clay which is present. Lignin determinations were made with some of the organic matter. These are given in Table 4. Analyses are according to the method of Steiner and Meloche. Results are only approximate.

TABLE 3. Organic Contents of Sediments of Cores B, E and F as Determined through Loss on Ignition.

Sample Number	Organic Matter
B Ekman	62.6%
1	68.2
2	66.2
3	63.5
4	62.8
5	49.6
6	47.0
7	51.7
8	27.0
10	55.5
E Ekman	45.0
2	44.0
3	3.5
Bottom of 3	2.7
F Ekman	66
2	78
6	63
8	61
10	61
13	66

The figures show that in the organic-rich sediments the loss on ignition is around 50 per cent. In Core B, it is a little greater than 55 per cent. The low figure in B-8 is not understood. Mr. McKelvey's figures for loss on ignition are generally larger than those of Mr. Carter. It is thought that this is due to less complete elimination of water before ignition. Analyses by Mr. Carter are given in Table 3.

The lignin content of the organic matter of Cores A, B, D and F is given in Table 4. The determinations were made by Mr. McKelvey.

TABLE 4. Lignin Content of Sediments of Cores A, B, D, and F.

Sample Number	Per Cent Lignin in organic matter			
	Core A	Core B	Core D	Core F
1-2	34.85%	27.20%	31.60%	13.15% (1); 26.00% (2)
4		31.30		
6	40.07	28.50	21.20	21.60
8	46.10	25.00	19.15 19.85	17.00
10		15.00	15.35 12.45	12.40
11		37.20		
13				7.05

The analyses indicate that, in general, something less than one-half of the organic matter is in the form of lignin.

There seems to be little in the figures relating to organic matter which indicates anything of significance. The low percentage of organic matter in sediments deposited before the covering of the surrounding region with vegetation is shown in E-3 as contrasted with figures given for the organic-rich sediments of Core B. It was assumed that the lignin content would increase with depth because of bacterial elimination of the proteins and cellulose. This seems to be indicated by the figures of Core B, but is not sustained by those of Core F.

More or less complete chemical analyses of the sediments gave Mr. Carter the results shown in Table 5.

TABLE 5. Chemical Composition of Sediments of Cores A, C, and D.

Sample Number	Al	Fe_3	Fe_2	SiO_2	Loss on Ignition	Soluble in: Chloroform	Soluble in: Ether
A Ekman	7.89	0.68	8.09	27.53	40.18	1.96	1.13
2	8.15	0.93	1.45	28.92	40.62	1.30	1.00
4	8.42	0.49	1.90	35.37	52.07	1.08	0.70
6	2.70	0.72	2.80	33.94	51.00	0.87	0.59
8	7.05	1.13	2.60	30.53	43.15	1.70	0.40
C Ekman	7.50	0.89	1.96	28.90	36.09	2.02	1.32
2	5.15	1.02	1.61	24.54	34.64	1.86	1.26
4	3.73	1.39	0.90	25.54	56.89	2.80	1.24
6	4.26	1.30	1.89	35.33	51.23	1.30	0.86
8	4.99	1.32	1.71	37.00	51.02	0.52	0.56
10	3.99	1.46	2.38	26.61	43.73	1.97	0.50
D Ekman	5.45	0.60	2.15	27.74	33.96	1.90	1.13
2	5.79	0.64	1.94	28.27	37.91	2.37	1.12
4	5.13	1.01	1.97	18.71	51.99	1.43	0.82
8	4.31	1.10	2.30	26.94	52.23	1.66	0.90
10	3.30	1.11	2.40	26.61	46.69	0.57	0.71

The tables indicate that the ferric iron decreases with depth which is to be expected because of reduction of ferric compounds by bacterial decomposition of organic matter. The ferrous iron seems to be variable in distribution and it does not change complementary to the ferric iron. As compounds of ferrous iron are more or less soluble it would be possible for them to move in the waters permeating the sediments. The quantities of both forms of iron are small. The aluminum is generally greater in the higher parts of the column and declines somewhat with depth. The reason for this is not known unless it is associated with the human agricultural period which permitted more dust to drop from the atmosphere. Silica is

greatly variable in its distribution, which is what should be expected considering the three possible derivations—inorganic sediments, sponge spicules, and diatoms. The sediments also contain traces of calcium, magnesium, manganese, sodium, potassium, and phosphorus.

The quantity of oils in the sediments was not determined with a great deal of precision and more is present than the figures indicate. There seems to be little correlation between the loss on ignition and the quantity of oils determined.

Compacting and lithification of the sediments in Nebish Lake would produce a thickness of a half to a meter of sediments over the deep parts of the basin and less than a third of a meter about the margins. The sediments over the deep parts of the basin would be black shales rich in organic matter and these would pass outward into sands and gravels over those parts of the present basin which are less than about two meters deep. There would be places, however, where tongues of clayey, sandy, or gravelly sediments would extend into what formerly were deeper parts of the basin as shown by the sediments encountered in Core E in water of the depth of about six meters or 20 feet. The deposits were made since retirement of the Wisconsin glacier some 25,000 to 50,000 years ago. This gives a maximum rate of deposition of compacted sediments of a meter in 50,000 to 100,000 years.

LITTLE JOHN LAKE AND ITS SEDIMENTS.

The position of Little John Lake and its relations to the other lakes considered in this paper are shown on Fig. 1. Its area is about 100 acres and the shores are composed of sands and gravels. The greatest depth of water in the lake, 6.3 meters or about 21 feet, is just north of the peninsula on the north end.

The sediments over the bottom of Little John Lake below the depth of about three meters are largely of organic origin and the organic material consists mostly of pale greenish-yellow gel in which are enmeshed conifer needles, pollen grains, and pieces of leaves, bark and stems. There are also sponge spicules, diatom tests, and particles of quartz and other minerals. Few of the inorganic particles in the organic-rich sediments show much rounding. Some of the organic sediments originated in the lake, others were derived from the vegetation on the land surrounding the lake. It has not been possible to evaluate the

contributions from the two sources. These organic sediments seem to be typical gyttja.

Sands and gravels cover the bottoms adjacent to the shore from which the inorganic sediments were largely derived. It is also probable that most of the inorganic components of the gyttja were derived from the shores. Some inorganic sediments must have fallen from the atmosphere.

The waters of Little John Lake are soft and evidently are oligotrophic. Materials in solution are of small quantity and of about the same qualitative and quantitative importance as in the waters of other woodland lakes of the region. Quantities are somewhat larger than in Nebish Lake. Studies by the Trout Lake Limnological Laboratory have shown that the waters contain 17.80 milligrams of magnesium per liter.

The lake contains few shelled invertebrates and no shells were found in any of the samples collected. This is in keeping with the situation in other small woodland lakes of the region.

Samples to the number of 41 were obtained from the bottom of Little John Lake by means of the Ekman dredge. These were taken along five ranges, as shown in Fig. 4. Six core sam-

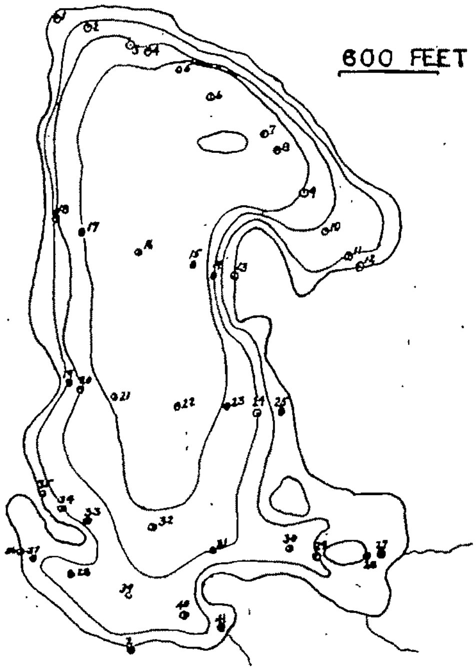

FIG. 4. Little John Lake, showing station of sampling with the Ekman dredge.

ples were obtained from positions shown on the map of Fig. 5 and the same map shows the stations from which the sediments were sampled by means of a spud sampler.

FIG. 5. Little John Lake, showing stations of sampling with the spud sampler and the stations from which cores were obtained. Stations of cores are indicated by capital letters.

Mechanical analyses of the fine-grained organic-rich sediments from the deeper parts of the lake were not made as it has been found that analyses of such sediments have little or no sedimentational significance. The samples contain large quantities of microscopic plant material and all particles are enmeshed in a pale greenish-yellow gel from which it is difficult to separate them. Elimination of the organic matter can be done, but other things are also eliminated. Analyses of the sediments from the shallow waters adjacent to the shores are given in Table 6. These sediments do not contain much organic matter.

TABLE 6. Mechanical Analyses of the Shallow Water Sediments of Little John Lake.

Sample Number	Depth of water	over 4 mm.	2-4 mm.	1-2 mm.	½-1 mm.
1	0.33 m.	41.70%	9.63%	3.91%	5.55%
2	1.50	0.13	4.78	10.04	15.68
3	4.50	0.00	1.19	2.91	12.10
9	5.00	1.72	3.27	4.17	21.15
13	0.33	0.75	1.43	2.86	8.14
14	3.00	0.90	2.89	3.82	18.00
19	0.33	4.60	2.83	2.78	18.75
20	4.00	3.68	5.83	5.24	18.82
24 Rocky bottom	2.50	2.95	5.32	5.10	18.90
25 Gravel beach	0.50	4.40	8.06	4.31	18.25
29 Rocky bottom	1.50	56.00	12.40	8.10	9.05
34	3.50	1.47	7.69	12.09	21.90
35	1.00	5.40	7.00	9.95	16.90
41	0.50	0.33	1.39	2.32	9.04

¼-½ mm.	⅛-¼ mm.	1/16-⅛ mm.	less than 1/16 mm.	Q1	M	Q3	So	Sk
15.70%	17.15%	5.50%	0.98%	5.60	2.30	0.55	3.2	.58
38.42	27.42	3.65	0.19	0.67	0.37	0.22	1.7	1.07
53.40	26.90	3.31	0.32	0.45	0.34	0.22	1.4	.86
60.25	9.10	0.29	0.10	0.60	0.42	0.32	1.3	1.09
57.60	27.05	1.58	0.18	0.37	0.34	0.23	1.3	.74
57.30	20.30	1.64	0.17	0.48	0.36	0.26	1.4	.96
46.80	16.83	6.75	1.57	0.60	0.41	0.31	1.4	1.16
47.30	19.45	4.13	0.51	0.62	0.42	0.25	1.6	.87
50.30	21.70	1.30	0.11	0.55	0.36	0.25	1.5	1.06
48.50	23.90	2.34	0.18	0.50	0.38	0.24	1.4	.83
10.30	2.92	1.08	0.00	6.20	4.40	2.70	1.5	.91
42.20	14.40	1.18	0.23	0.85	0.45	0.30	1.7	1.26
44.50	15.30	0.91	0.09	0.92	0.44	0.30	1.8	1.42
46.80	31.20	7.10	1.01	0.44	0.28	0.18	1.5	1.50

The analyses show the great differences in the sediments for the same depths and the variations in depths over which sediments of like dimensions are distributed. It should be noted that sediments of the coarseness indicated by samples 1 and 29 were collected at depths of 0.33 and 1.5 meters respectively and that at other places of these depths the sediments are by no means as coarse as may be seen by comparing sample 1 with 13 or 19 and sample 20 with sample 2. The analyses do not show the contrasts as great as they really are, as sample 29 was taken from a rocky bottom whereas sample 2 was taken from a sandy bottom. This is the case in a small lake where the inorganic sediments have a somewhat common source in outwash deposits. It is known that the contrasts in a large

lake have even greater magnitudes as work to be later published on the sediments of the large Trout Lake will show.

An interesting feature is the narrow range of the physical constants, as is shown in the last five columns of Table 6. With the exception of samples 29, 34, and 35, all fall in a relatively narrow range. The coefficients of sorting of all samples except number 1 are in the range from 1.3 to 1.8. All samples excepting numbers 1, 34, 35, and 41 have the skewness in a close range. It is suggested that these similarities are largely due to the fact that the outwash deposits over any part of the shores are reasonably well sorted and thus the sediments derived from these deposits would exhibit a somewhat like degree of sorting.

The spud sampler was used to determine the thickness of the sediments in Little John Lake. Results were not very successful. Twenty-five soundings on five ranges were made, as shown on Fig. 5. The sediments were found to exceed a thickness of 4.9 meters, about 16 feet, in only four places and to exceed 4.6 meters, about 15 feet, in two additional places. In one place the original bottom of the basin is thought to have been reached at five meters. As the sediments contain approximately 95 per cent water, it follows that the total thickness on compaction would approximate about a third of a meter, or a rate of deposition of about a meter in 75,000 years or more. Results of the spud sampling are described below. The last figure in connection with each station gives the maximum depth penetrated by the sampler. The bottom of the sediments which have accumulated since the establishment of vegetation in the region is thought not to have been reached at 10 stations. The last figure given at each station is the depth penetrated.

Range 1

No. 1. Water 0.6 meter deep.

0 to .8 meter, greenish-brown gyttja, no plant fibers and no sand.

.8 to 1.8 meters, brown peat. The original bottom of the lake is evidently on top of the peat.

No. 2. Water 2.5 meters deep.

0 to 2.4 meters, greenish-brown gyttja.

2.4 to 2.5 meters, pinking-gray very fine sand and silt.

No. 3. Water 3 meters deep.
0 to 5 meters, greenish-brown gyttja with a little silt in lowest part.

No. 4. Water 4 meters deep.
0 to 3 meters, greenish-gray gyttja with some sand.
3 to 3.6 meters, gray silty clay without organic matter.

No. 5. Water 2 meters deep.
0 to .76 meter, fine sand with some organic matter.
.76 to 1.5 meters, gray sand with some particles to 2 mm. in diameter with silt and organic matter in upper part, silty clay below without organic matter.

Range 2

No. 6. Water 4 meters deep.
0 to 1.5 meters, greenish-gray gyttja.
1.5 to 2.1 meters, greenish-brown organic matter which is peat like.
2.1 to 2.6 meters, gray sand and silt with pinkish-gray silt and clay at base.

No. 7. Water 5 meters deep.
0–3.75 meters. Greenish-gray gyttja.

No. 8. Water 5 meters deep.
0–4.65 meters, greenish-gray gyttja.

No. 9. Water 4.2 meters deep.
0–4.92 meters. Greenish-brown gyttja.

No. 10. Water 1 meter deep.
0–4.41 meters. Greenish-brown gyttja with much plant matter.
4.41–5.10 meters. Light-brown organic matter, hardly gyttja, rests on pinkish-gray sand without organic matter.

Range 3

No. 11. Water 4.66 meters deep.
0–1.5 meters. Gray sand and silt with much plant matter in top half.

No. 12. Water 6 meters deep.
0–3.9 meters. Greenish-brown gyttja.

No. 13. Water 6 meters deep.
0–4.5 meters. Greenish-brown gyttja.

No. 14. Water 5.66 meters deep.
0–4.8 meters. Greenish-gray or greenish-brown gyttja.

No. 15. Water 5 meters deep.
Bottom medium grained gray sand.

Range 4

No. 16. Water 4 meters deep.
Bottom medium grained, gray sand with some organic matter.

No. 17. Water 6 meters deep.
0–3.9 meters. Greenish-gray gyttja.

No. 18. Water 6 meters deep.
0–4.28 meters. Greenish-gray gyttja with some plant fiber at the depth of 3.15 meters.

No. 19. Water 6 meters deep.
0–4.5 meters. Greenish gray to greenish-brown gyttja.

No. 20. Water 6.48 meters deep.
0–1.68 meters. Greenish-gray gyttja resting on about a half meter of gray sand beneath which is pinkish-gray sand without organic matter.

Range 5

No. 21. Depth of water 4.5 meters.
0–1.8 meters. Greenish-gray gyttja with much plant matter and sand, rests on pinkish-gray sand and silt.

No. 22. Water 5.66 meters deep.
0–4.2 meters. Greenish-gray gyttja.

No. 23. Water 6.38 meters deep.
0–4.5 meters. Greenish-gray gyttja.

No. 24. Water 6 meters deep.
0–4 meters. Greenish-gray gyttja.

No. 25. Water 5 meters deep.
0–.75 meter. Greenish-gray gyttja with some sand. Rests on about a third of a meter of gray sand with organic matter which in turn rests on pinkish-gray sand without organic matter.

Tabulation of the depth of water and the thickness of the organic-rich sediments gives results as follows. The plus sign indicates that the total thickness of the sediments is not known in that the complete thickness was not penetrated by the sampler. Reference to the map of Fig. 5 shows that the stations where the organic sediments were not penetrated generally represent the central as well as the deeper parts of the present basin and presumably the deepest water was found at station 20, but the organic-rich sediments at the place have a thickness of only 1.68 meters. The greatest determined thickness of the organic sediments was found at station 10 with 5.9 meters with

the water only a meter deep. This place evidently represents a deep hole in the original basin.

TABLE 7. Thickness of sediments as shown by spud sampling.

Station	Depth of water	Thickness of organic sediments
1	0.6 meters	0.8 meters
2	2.5	2.5
3	3.0	5.0+
4	4.0	3.6
5	2.0	0.0
6	2.1	2.1
7	5.0	3.75+
8	5.0	4.65+
9	4.2	4.92+
10	1.0	5.9
11	4.66	1.5
12	6.0	3.9+
13	6.0	4.5+
14	5.66	4.8+
15	5.0	0.0
16	4.0	0.0
17	6.0	3.9+
18	6.0	4.28+
19	6.0	4.5+
20	6.48	1.68
21	4.5	1.8
22	5.66	4.2+
23	6.33	4.5+
24	6.0	4.0+
25	5.0	0.75

The characters of the sediments in the core samples are given below. The stations of acquirement are shown in Fig. 5.

Core A. Was taken at the depth of water of one-third meter and the core extended into sediments to the depth of 1.8 meters.

Core B. Acquired in water of depth of 2.94 meters. Gyttja was present in the core to depth of 0.6 meter. Peat lay below this to the thickness of 0.36 meter. This had pinkish-green gyttja below. The total thickness of the organic sediments was 4.3 meters with an unknown thickness below.

Core C. Core C was acquired in water of 5.2 meters depth. Gyttja extended to the depth of 3.6 meters and the sampler penetrated an additional 0.36 meter in peat.

Core D. The water at the place of acquirement was 5.7 meters deep and the gyttja was penetrated to the depth of 5.7 meters without reaching to the bottom of this form of sediment.

Core E. This core was taken where the water was 6.06

meters deep. The gyttja was penetrated to the depth of 3.6 meters without reaching bottom.

Chemical analyses of the sediments of the cores was not made as it was felt that these would not be greatly different from those of Nebish, Grassy, or Little Long Lake. Neither were mechanical analyses of the sediments of the cores made as the results seemed valueless from the point of view of sedimentation.

Ether extracts made of the sediments of the cores and the Ekman samples from the positions of the cores gave the results shown in Table 8.

TABLE 8. Ether extracts of the samples of the cores and Ekman samples at the places of the cores. The letters BC indicate bottom of core.

Number of sample. Each represents 1 foot of depth.	Core B	Core C	Core D	Core E	Core F
Ekman	0.41%	0.64%	0.60%	0.50%	0.84%
1	0.41	0.14	...	...	0.20
2	0.41	0.44	1.01	...	0.93
3	0.12	0.56	...	0.37	0.36
4	0.20	...	...	...	0.72
5	0.90	...	0.27	0.51	0.54
6	0.50	0.48	1.07	...	0.28
7	1.01	1.18	0.44	...	0.40
8	0.16	0.58	0.29	...	0.32
9	0.77	...	0.40	0.39	0.62
10	...	0.47	...	0.38	0.32
11	1.25	0.22BC	0.41BC	0.24	...
12	1.15BC			0.87BC	0.27
13					0.44
Average	0.61	0.41	0.43	0.46	0.44

The ether extracts average 0.47 per cent of the dry weight of the sediments which is equivalent to only 9.4 pounds of oily matter per ton. The range is from 2.4 pounds per ton in core B3 to 25 pounds per ton in B11. There seems to be no trend in the distribution, except the highest yields in core B were found in the lowest part of the core and such is also the case in core C. There is no doubt that extraction by means of destructive distillation would have yielded a larger quantity of oily matter.

[To be Continued.]

THE SPECIES CONCEPT IN PETROLOGY.

S. J. SHAND.

ABSTRACT. The species concept was introduced into petrology by Linnaeus. In the 19th century the preoccupation of naturalists with the origin of species fostered a pseudo-biological attitude toward petrogenesis, which resulted in the theory of spontaneous magmatic differentiation. The subsequent development of physical chemistry has thrown new light on the subject, but petrographers continue to think in terms of natural species and their supposed affinities. A science which is concerned with phase reactions and shifting equilibria in a chemical system can no longer permit itself to be hampered by traditional names, ill-defined species, and obsolete genetic theories.

IN the history of petrology we may recognize four significant periods, defined with some latitude by the dates 1770, 1820, 1860, and 1910. These may be characterized as the Linnaean period, the period of analytical chemistry, the pseudo-Darwinian period, and the period of physical chemistry.

The year 1770 records the tenth edition of the *Systema Naturae* of Linnaeus. In this famous work Linnaeus applied to minerals and rocks the same device of classes, orders, genera, and species that he used for living things. In the kingdom *Minerae*, for example, and in the class *Petrae*, order *Aggregata*, we find the genus *Saxum* with many species such as these:

> Saxum impalpabile, striis punctis maculisque sparsis spatosis.
> Specific name, *porphyrius*.
> Saxum impalpabile schistum subcalcarium, fragmentis rhombicis.
> Specific name, *trapp*.
> Saxum spatosum quartzosum micaceumque rufescens.
> Specific name, *granites*.

The merit of the Linnaean system, as applied to plants, lay in the demonstration that species possess fixed characters which are capable of precise definition. By extending to rocks a system of classification and a set of terms that were originally devised for plants, Linnaeus fostered the idea that rocks too possess fixed characters which can be determined by simple inspection. But the Linnaean or natural history method of classification has a fundamental weakness which was pointed out by Whewell in these words:

> The natural history classifiers, in studying the external characters of bodies, take for granted that they can, without any

> other light, discover the relative value and importance of these characters. The grouping of species into a genus, of genera into an order, according to the method of this school, proceeds by no definite rules but by a latent talent of appreciation—a sort of classifying instinct.

The classifying instinct which served Linnaeus so well in the case of plants, failed him completely when he applied it to rocks. The explanation is simple: before one can form a useful classification of a set of objects he must know enough about them to be able to distinguish important characters from unimportant; and neither Linnaeus nor any of his contemporaries had more than a superficial knowledge of rocks.

Although the Linnaean classification of rocks has long been forgotten, the concept of rock-species survives to this day. Petrographers still erect new species (or types, as many prefer to call them) with little more than a classifying instinct as their guide. This seems an appropriate moment to recall the criticism of Van Hise, who wrote in 1899 that

> The method of petrographers in proposing names, so far as any method is discoverable, is to give an independent name to each rock which is slightly different from any previous rock found, without reference to any definite plan of nomenclature.

To say that rock names represent types, not species, is just quibbling. A type is the pattern of a group, and a group of objects having common characteristics is a species.

In the first half of the 19th century the science of mineralogy made spectacular advances at the hands of Berzelius, Mitscherlich, and other brilliant chemists. It was natural that rocks as well as minerals should attract their attention. Abich, Bunsen, Delesse, Kjerulf, Rammelsberg, Streng, and their students made many bulk analyses of rocks, and from the analytical data they computed atomic ratios, oxygen quotients, and even tentative chemical formulae. This was a radical departure from the method of Linnaeus, and one may fairly say that at this time the study of rocks had passed from the hands of the naturalists into those of the chemists. Bischof's *Chemical Geology* (1847) contains many analyses of rocks, and in 1861 Justus Roth published a compilation of more than 900 analyses, mostly of eruptive rocks. But out of all this work there came no proposal for a chemical classification of rocks, other than mere arithmetical arrangements based on silica percentages and the oxygen quotient.

The history of petrology might have been very different if this enthusiasm for chemistry had been joined with adequate microscopical work. The microscope had been used for some time, but only to study polished surfaces and crushed grains. The first thin sections of rocks were made by Nicol about 1830, but Nicol's technique did not become generally known till thirty years later. By this delay a great opportunity was lost. After the discovery of the aniline dyes by Perkin in 1856, the attention of the majority of chemists was diverted from the mineral field to the new and wonderful field of synthetic organic chemistry, with its rich commercial possibilities. All the common minerals had already been analyzed; new minerals were rarely discovered; and Justus Roth had clearly indicated his disbelief in the possibility of making further advances by the chemical analysis of rocks. To many chemists it must have seemed that mineral chemistry was worked out. Except in France, the synthesis of minerals and rocks fell into abeyance.

At this time Charles Darwin was at the height of his power, and was teaching the fascinating doctrine of evolution and the origin of species (1859). The new ideas had a tremendous attraction for students of natural history, and Roth has recorded that there was among geologists "eine vorherrschende Neigung für Paläontologie." So it came about that the awakening science of petrology, abandoned by its chemical nursemaid, was left in the hands of a generation of geologists whose training as well as their interest tended more toward biology than chemistry. It is not surprising that they should have looked at rocks with the eyes of Linnaeus rather than Bunsen; that they should have seen "natural species" among rocks as Linnaeus had done; and should have tried to erect "genetic trees" for them in imitation of Darwin. The species concept came to life again, and the link with chemistry was broken.

These pseudo-Darwinian ideas found their fullest expression in the doctrine of "magmatische Spaltung" (magmatic differentiation) introduced by Rosenbusch in 1890. According to this teaching, a homogeneous primordial magma gives rise by a spontaneous process of splitting to a series of chemically distinct secondary magmas,[1] each of which, upon its intrusion into the higher levels of the earth-crust, undergoes a further

[1] "Man wird unter Spaltung den spontanen Zerfall eines chemisch gleichartigen Gesammtmagmas in zwei oder mehrere chemisch differente Theilmagmen verstehen mussen."

spontaneous differentiation, once or oftener, until all the recognized species of eruptive rocks have been generated. (Rosenbusch did not use the word species but *Gesteinstypus*, which has the same meaning.) In this "spontaneous splitting of the magma" there is something reminiscent of the old biological fallacy of spontaneous generation.

Belief in the existence of natural types or species led inevitably to the search for new species. Zirkel in 1893 indexed 139 single-word names of specific character. Rosenbusch in 1907 listed 304 such names. In 1935, Tröger recorded 634 of these specialized names, and at the time of writing the number has swelled to nearly 700, besides many compound names.

The authors of these names have seldom observed the warning which Linnaeus gave to botanists in 1753:

> I beseech all sane botanists to avoid most religiously ever proposing a trivial name without a sufficient specific distinction, lest the science should fall into its former barbarism.

One need only glance through a compendium of rock names (Kemp, or Holmes, or Tröger) to see that rock types or species have been set up on the most indefinite, trivial, and fanciful grounds. Few indeed of the nearly 700 types show the "sufficient specific distinction" that Linnaeus demanded.

The species concept has not only imposed on us a plague of unjustified and largely unintelligible rock names,[2] but the search for "affinities" between one species and another has played havoc with all attempts at a logical classification of rocks. Examples of the absurdities into which petrographers have been led by the search for "affinities" are not hard to find. A South African geologist, confronted some forty years ago with a rock which seemed to contain both nepheline and hypersthene in a granophyric groundmass, was led to speculate thus:

> [The rock] shows perhaps a certain affinity to the nepheline syenites, which are known to occur in connection with the same general igneous series with which this rock is associated, while the high proportion of micropegmatite allies it to the

[2] Every petrologist who has racked his brain to remember the meaning of bekinkinite or tsingtauite, leeuwfonteinite or uncompahgrite, will appreciate the humor of Gevers and Dunne who said in a recent paper that they had "refrained from coining new names such as isandhlundhluite and umkandandhluite" for certain granodioritic rocks in Natal.

> finer-grained varieties of the Bushveld granite; the hypersthene, on the other hand, tending to connect it with the norites.

Rosenbusch himself was guilty of similar absurdities, for example, in his discussion of the systematic position of monzonite, which he compared in turn with the alkali-syenites, the alkali-lime syenites, and the essexites. While admitting the presence of abundant plagioclase along with the orthoclase in this rock, he claimed that it would be inadmissible to connect monzonite with banatite and adamellite because to do só would "obscure the natural relationships of the rock."[3] Observing that the dominant dark mineral in monzonite is a diopsidic pyroxene, he ruled that this is "without significance in determining the natural position of the rock." Having in this arbitrary way excluded all evidence unfavorable to his view, Rosenbusch concluded that monzonite is an alkali-syenite. In this as in many other sections of his great work it stands out clearly that Rosenbusch was guided by a "classifying instinct" which could override any consideration of mineralogy or chemistry. His petrogenetic ideas owe more to the influence of Linnaeus and Darwin than to the meticulous chemical studies of Berzelius, Bischof, Bunsen, and Roth.

Rosenbusch's attitude toward chemistry is clearly indicated by passages such as the following:

> Es lässt sich keineswegs in allen Fällen aus der Analyse eines Granites oder Syenites erkennen, ob ein Glied der foyaitischen oder der granito-dioritischen Gesteinsreihe vorliegt.
>
> Wollte man jeden alkalireichen, an CaO und MgO armen Granit einen Alkaligranit nennen, wie es stellenweise geschieht, so würde man zerreissen was die Natur verbunden hat und sich an dem Geiste der Geologie versündigen.

In short, if chemistry does not fall into line with the classifying instinct, so much the worse for chemistry!

Meanwhile great advances were being made by chemists in the study of solutions. Guthrie in 1875 established the nature of eutectic mixtures, and Gibbs announced the phase rule in 1876. These events seem to have passed unnoticed by contemporary petrographers, for it was not till 1888 that Teall

[3] "Man verkennt die natürliche Verwandschaft und geologische Zusammengehörigkeit, wenn man eine Reihe Monzonit-Banatit-Adamellit aufstellt."

made the suggestion that graphic intergrowths such as micropegmatite may be eutectic mixtures, and not till 1901 that Becker suggested a classification of rocks on an eutectic basis. Certainly the new discoveries had no effect on systematic petrography, which was dominated more and more completely by Rosenbusch and his doctrine of natural affinities. The strictly objective classification of Ferdinand Zirkel was driven into the background. New specific names were coined on the slenderest grounds. Almost every petrographic thesis announced the discovery of a new rock type.

But glimpses of a new petrology enlightened by physical chemistry were now to be seen. J. H. L. Vogt began in 1884 a great series of studies on slags which led him more and more to look at rocks in the light of the laws of solution. Iddings in 1892 and Harker in 1896 discussed the chemistry of rock formation in essays of a tentative character. Vogt's *Silikatschmelzlösungen* appeared in 1903, his *Kristallisationsfolge in Eruptivgesteinen* in 1906, and Doelter's *Petrogenesis* in the same year. In all these publications the physico-chemical approach was used. Spontaneous differentiation of the magma is ignored, and rock species and natural affinities are scarcely mentioned. Instead, eutectic ratios, fractional crystallization, rate of diffusion, corrosion and assimilation, and other purely physical and chemical considerations form the subject of discussion. In 1910 the new ideas were consolidated in Harker's *Natural History of Igneous Rocks* and in the first volume of Iddings' *Igneous Rocks*.

By the year 1910 it should have been clear to everybody that petrology had found its place among the sciences, and that that place lay in the domain of physical chemistry. But petrographers in general showed no awareness of this and carried on their activities exactly as before. Between 1910 and 1942 no less than 223 new specific names were coined to indicate "new types," most of which have no better justification than the species set up by Linnaeus in 1770.

It is true that a revolt against Rosenbuschian petrography began in 1903 with the appearance of the Norm classification. This was a forward step in so far as it emphasized the importance of chemistry, but a backward step inasmuch as analytical instead of physical chemistry formed the basis of classification. It was a fundamental error to suppose that a chemical system can be discussed in terms of its components alone.

without regard to the phases. Since 1910 more than twenty other schemes of classification have been proposed, and almost all of them ignore physical chemistry as if the authors had never heard of such a thing. One might think that the petrographers and the geochemists of this period had lived in different worlds.

What is the object of classification? According to Mill it is

> To provide that things shall be thought of in such groups, and these groups in such an order, as will best conduce to the remembrance and to the ascertainment of their laws.

It follows that the classification of a set of objects must keep pace with the understanding of them. When a new law is discovered or an old belief disproved, the classification must be modified accordingly. Here is the root of our trouble; there is a lag of some eighty years between the science of petrology and the classification of rocks. It has been urged against this view that the Linnaean classification of plants has needed no modification for 200 years. But the reason why the Linnaean system has endured so long is that Linnaeus began by making an exhaustive study of the characters of plants in order to assess their relative importance. There had been other classifications before his time, but he rejected all of them and began afresh.

No such careful evaluation of characters preceded the generally accepted mineralogical classification of rocks. It just grew up, like a cairn on a hilltop to which every climber adds a stone as his contribution. Petrography at the present time is in just such a chaotic state as botany before the time of Linnaeus. The remedy is the same: to discard existing systems and begin afresh by deciding which characters are important and which less important in the light of the physical chemistry of rock formation. The first step must be the realization that the species concept of Linnaeus and the classifying instinct of Rosenbusch have led us astray. There are no natural species (call them types or what you will) among rocks except such as are indicated and defined by physical chemistry. A classifying instinct is not of the slightest use in solving chemical problems. Ergo, most of our specific names must be scrapped, and the tangled web of "natural affinities" along with them.

If we are agreed to regard a rock-magma as a chemical

system (and what else can we do?) then we must classify rocks as we do other chemical systems; that is, with regard only to components, phases, and cooling-history. Petrology is a historical science, but its family tree is a chemical flow-sheet.

Does this mean that petrology must be taken out of the hands of geologists? By no means. Geological evidence is indispensable for interpreting the cooling-history of a rock. The magma is a chemical system; but it is an open system, not a closed one such as chemists have chiefly studied. In the cooling of the system many things have happened, such as reaction with the wall rocks; separation of crystalline phases by sinking or flotation; rapid changes of temperature, pressure, and environment; loss of fugitive constituents; and only the geologist working in the field can furnish direct evidence of these changing conditions. Petrology cannot afford to relax its ties with field geology; on the contrary, geological observation and chemical theory need to be correlated more closely than ever in order to decipher the cooling history of a rock mass. But a petrology that is concerned with phase reactions and shifting equilibria can no longer be hampered by traditional names, ill-defined species, and dubious genetic theories. Petrologists must free themselves from the chains of the species concept and the domination of the classifying instinct.

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SCIENTIFIC INTELLIGENCE

Physics.

General Physics; by OSWALD BLACKWOOD. Pp. viii, 622; 524 figs. New York, 1948 (John Wiley and Sons, $3.75).—The book is a college text designed for introductory courses. It reproduces many of the features of the author's earlier "Introductory College Physics," but has a greater number of illustrations and problems. New material on modern physics has been added and many of the older subjects have been brought up to date.

It is impossible for a reviewer to pronounce judgment as to the quality of an elementary text without first using it in class. I have used Blackwood's former book and found it very satisfactory. The present volume appears to be an improvement on the old; it would therefore seem to hold great promise as an unusually thoughtful and teachable textbook on the freshman and sophomore level. The book does not employ calculus. HENRY MARGENAU.

Treatment of Experimental Data; by ARCHIE G. WORTHING and JOSEPH GEFFNER. Pp. ix, 342. New York, 1943 (John Wiley and Sons, $4.50).—The book departs from the usual treatments of adjustment of data and theory of errors in several important and noteworthy respects. First, it is not so much an orthodox systematic development of the work in these fields, but a lucid and most readable presentation of useful procedures flavored and annotated by the authors, handled with a degree of skill that can come only from wide experience in actively applying and teaching the subject. Second, the treatment abounds with well chosen modern examples which alleviate the learning of rules. Last, but not least, the book impresses by the frankness and adroitness with which the authors call attention to common mistakes and fallacies to which experimenters are prone. Their willingness to devote considerable attention to such shortcomings and to guide the experimenter by giving practical hints and detailed advice are among the features which make the book wholesome and commendable.

The degree of difficulty is such that the text can be read with ease by students who have mastered the calculus. Considerable effort is devoted to simplification of mathematical matters, and the point of view of the experimenter is maintained throughout. As to contents, considerable space is given to the representation of data by tables, graphs, and equations. Numerical and graphical methods of differentiation and integration are treated. The discussion of Fourier series, the Gaussian frequency distribution, and the usual theory of errors forms the central part of the book, and the method

of least squares is amplified by numerous examples and problems. Of interest to physicists and chemists should be the chapter on correlations which, though useful, is not often stressed in books of this sort. An appendix contains a simple treatment of determinants, easily readable and helpful to the uninitiated.

The authors' feeling, expressed in the preface, that the book has a worthwhile message for physicists, chemists and engineers seems well substantiated to this reviewer. HENRY MARGENAU.

Practical Physics; *by* M. W. WHITE, Editor; K. V. MANNING, R. L. WEBER, R. O. CORNETT, and others. Pp. x, 365; many figs. Pennsylvania State College Industrial Series. New York, 1943 (McGraw-Hill Book Co. $2.50).—The book is an elementary, practical, and abbreviated text in introductory general physics at the freshman level, that meets a pressing and specific need created under wartime conditions by streamlined courses, shortened hours, and special service-group and adult training courses. Primary emphasis is placed upon the basic principles of those portions of physics that are of immediate, practical use in war industry, technical work, and the Armed Services.

The order in which the various topics are treated is somewhat unorthodox. After an introduction on units, measurements and errors, the book discusses temperature and various thermal phenomena, then leads the reader via the properties of solids into meteorology. After this it takes up some problems of mechanics. One quarter of the book is devoted to electricity. All of acoustics and optics is compressed into 58 pages.

The book appeals through the clarity and suggestiveness of its diagrams. Its discourse never fails to be lucid and to the point.

HENRY MARGENAU.

CHEMISTRY.

Bibliography of References to the Literature on the Minor Elements. Fourth Supplement to the Third Edition. Originally compiled by L. G. Willis. Pp. 1-92. New York, 1943 (Chilean Nitrate Educational Bureau).—This is the fourth supplement to the third edition. Element, botanical and author indexes are included.

GEORGE M. MURPHY.

General Inorganic Chemistry; by M. CANNON SNEAD and J. LEWIS MAYNARD. Pp. xviii, 1166; 180 figs., 189 tables. New York, 1942 (D. Van Nostrand Co., Inc., $4.50).—Although written as a text for an elementary chemistry course, the size of the book indicates that it cannot be covered in the usual time available. Nevertheless, a good student should be pleased to have material for further reading and reference. The teacher also is given greater

latitude in his choice of the contents of the course. The conventional physical chemistry, such as ionization theory and the chapters on the chemistry of individual elements are well written, modern and quite complete. More unusual is the appearance of chapters on coordination compounds, colloids, radioactivity, alloys and other intermetallic compounds, these topics being often slighted in elementary courses. The book therefore is unique in its field. This fact together with its general excellence and its low cost indicates that it will be very useful to many chemists.

GEORGE M. MURPHY.

MINERALOGY.

Minerals in World Affairs; by T. S. LOVERING. Pp. ix, 894; 40 illustrations. (Prentice-Hall, Inc., $4.00).—This is a book of timely interest since, as the author points out, mineral production has been instrumental in determining the course of history many times in the past and promises to be of increasing importance in the future. Particular attention is given to the following topics: factors which determine national power; economics of the mineral industries; the part played by minerals in history; the geology and geography of important minerals and their trade movements and volume; the influence of minerals in shaping recent events; and the outlook for the future. Discussion of the important industrial minerals covers their uses, substitutes, technology, geology, and important sources. Numerous tables of production figures are included as well as maps showing important localities.

The author has assembled in this volume an excellent account of the rôle played by minerals in world affairs. It is largely written in non-technical terms, and will be of value not only to economic geologists but to students in many other fields. GEORGE SWITZER.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Regional Geography of Anglo-America; by C. LANGDON WHITE and EDWIN J. FOSCUE. Pp. xxii, 898; 287 figs. New York, 1948 Prentice-Hall, $4.75).—Geographers are still far from being agreed as to just what geography is. By no means all would agree with Professors White and Foscue when they say "that geography is concerned with nature, physical and biological, only if it provides an environment for man, and it is concerned with man only in his relation with nature." This definition of geography provides no place for any such thing as plant or animal geography. In attempting to support it and to show the importance of regional geography, the authors have made the first part of their 900-page book so argumentative or purely historical that it is not so profitable for students as it might well be.

The real meat of the book begins with Chapter 4. From that point onward, the definition and the argument make no difference. The authors give us a good, straightforward account of the geographic regions of North America, with plenty of interesting facts, a good many which have not been commonly known hitherto. Some sections such as the account of the crowding of oil wells, orchards and cities into southern California are extremely well done. In most sections of the book each region is treated with an unusual degree of attention to the "physical setting," the historical development and the "outlook."

Any one section, when read by itself, is quite interesting. When successive sections are read at short intervals, however, one gets the feeling that there is a great deal of repetition, or at least of monotony. This arises partly from the fact that where so many regions are described, there must be many similarities. It arises also from the fact that almost the same outline has been used for a large part of the chapters. The introductory part is variously labelled as "physiography," "physical setting," "physical appearance," "terrain," and "appearance," but all of these are much the same. "The outlook," generally is that "the region has been and will continue to be . . . important," but some "problem regions" such as the Appalachian Uplands are recognized.

As in most first editions there are mistakes. On page 714, for example, the temperature graph for Los Angeles is 10° too low. There are also many statements which are open to question. For example (page 289), when the Cotton Belt was first settled did the colonists think "they were in a tropical country where it was assumed that white men could do no physical labor"? And is it correct to say that for this reason "Charleston and Savannah became great slave-importing cities"? Such statements stimulate thought, but need to be elaborated, or expressed more tentatively. On the whole, however, this is a good book but it needs to be corrected and abbreviated.

ELLSWORTH HUNTINGTON.

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THE MODE OF PRESERVATION OF PLANT FOSSILS AND ITS BEARING UPON THE PROBLEM OF COAL FORMATION.

A. KRYSHTOFOVICH.

ABSTRACT. Critical study of isolated plant fossils can throw light on problems of coal formation which are difficult to solve by a direct attack on coal itself. In the individual plant fragment, such as a limb or a leaf embedded in matrix, we can infer the original distribution of different types of plant tissue and may be able to determine what has happened to each since burial, but in coal the residue of diverse types of plant tissue are mixed in a confused mass. This paper discusses some of the special types of plant preservation that throw light on the alteration of plant tissues into coal.

INTRODUCTION.

THE study of fossil plants has as its aim the solution of such theoretical problems as the phylogeny of the vegetable kingdom and the restoration of past landscapes and climates of the Earth, and it also serves the practical needs of determining the stratigraphical relations of rock formations and the correlation of beds, especially those bearing coal seams. Here, as elsewhere, even the most theoretical considerations commonly turn out to be a reliable basis for practical objectives.

The work of recent decades has shown that the thorough examination and utilization of caustobioliths (combustible sediment) requires knowledge of the regime under which accumulation and diagenesis (anthracolithization) of the plant material took place during the whole process of coal making.

Thus far, the fundamental problems are still unsolved as to what types of plant tissue are principally responsible for making the coal seams, and what kinds of differences in the original plant material have resulted in the diversity of final products such as peat, brown coal, lignite, bituminous coal, jet, boghead coal, etc. Until now there has been an indecisive struggle between theories which would attribute a predominant rôle to lignine (Fischer-Schrader), to cellulose (Berle-Orlov),

to proteins (Terres), to oils and sapropelitic-humic matter (Stadnikov, Bertrand). The indecisive state of the question certainly depends to a large degree upon a lack of balance in investigation, inadequate methods, and a preponderant use of speculation instead of thorough examination of the actual materials.

The impetus which was given by Marie Stopes (1919) to the examination of the coal mass and its components (fusite, durite, clarite, and vitrite) has resulted in a vast literature during the last score of years and has created a new branch of coal science—the so-called petrography of coal.[1]

During the last twenty-five years, M. D. Zalessky has been a leader in working along this line in Soviet Russia, joined somewhat later by G. Zhemchuzhnikov, and they have a school of followers including Z. V. Ergolskaya, A. A. Luber, O. F. Gracheva, I. E. Waltz, E. S. Korzhenevskaya, S. N. Naumova, etc. However, until now, this rather one-sided study of the components and ingredients of coal has proved to be inadequate for a definite solution of the problems of coal making, and we observe a continuous growth of more and more new hypotheses, equally inadequate and indefinite (Terres, Duparc, Stadnikov, Mackenzie-Taylor, etc.), most of them based upon inadequate study of actual material.

This may be due in part to the fact that in a coal seam we observe its principal and minor components after they have already undergone a prolonged, or at any rate, a bistadial alteration: 1) the primary one—before, during, and just after accumulation of the vegetable material, and before its burial or any diastrophic influence; and 2) the secondary alteration—a result of rock pressure, temperature, time, and other factors of diastrophism, including dynamic and regional phenomena, which may be repeated several times. These secondary changes largely obliterate most of the significant initial features involved in coal making, such as the nature and properties of the primordial plant matter (lignine, cellulose, humic matter, etc.), the condition of autochthonous or allochthonous accumulation, the rôle of water during the process, etc.

[1] This should be called anthracography, for it has nothing to do with petrography, which has as its aim the study of the minerals composing the rocks, whereas the examination of coal has to do with discerning its form elements and materials of different composition, most of which are not real minerals.

Our difficulty would be greatly alleviated if we could select for study some isolated plant object, such as a shoot, a twig, a leaf, a stalk, a fruit, or a seed, for then we could be sure of the original distribution and the nature of the several plant tissues. We can easily imagine, for example, that the surface of a shoot was covered with cuticle and epiderm, or with cork, below which in regular order were distributed respective tissues such as parenchym, floem, xylem, pith, etc., each with its appropriate chemical composition. In addition, it would include such ingredients as resin, wax, oil, silica, and calcium oxalate crystals, and even sugar and starch. The regular distribution of these tissues, each with its distinct chemical composition in every individual plant body, makes clear their relation to the outer medium (water, mud, sand, etc.), showing decidedly whether they actually touched this external medium or were buried in the depth of plant tissues. Sometimes it was not the covering or external tissues that were in contact with the sediments but some inner ones, either along a longitudinal split or a transverse fracture, or when the plant fragment was already decorticated during transportation. The lithologic character of the enclosing rock and the composition of its fossil flora and fauna bear witness as to the medium and the environment in which deposition as well as the alteration of certain of the plant tissues was taking place. Just such an example is presented by jet. Since we can easily restore the conditions on the sea floor where the piece of wood was deposited and where it later was changed into this peculiar variety, we are able to indicate its history and the reasons for the bituminization of the wood, though possibly not all of the details are sufficiently clear. There are important advantages to such study of individual plant bodies as a basis for comparison with the plant stuff accumulated in a coal seam.

However, the individual plant bodies, having undergone alteration from their primordial status, do not always appear quite comprehensible with respect to their morphology and consequently their systematic position. Indeed, the exact identification of the fossil plants becomes successful when we know exactly with what part of a plant we are dealing and what alteration it has undergone. Only then are we able to restore the habitus of the whole plant or even of the parts in question. Sometimes, even when the plant preservation

seems to be perfect, it is most difficult to restore the organization of such comparatively simple structures as hollow shoots of the equisetans, with their appendages. Equally difficult to comprehend are some cases in which massive plant bodies, such as trunks, twigs, large seeds or fruits, have been replaced by sandy or silty rock so that they form casts, more or less exactly preserving the outlines but without any direct or true mineralization of the plant tissue. It is still more difficult to trace the origin and comprehend the nature of some plant remains known as "impressions" which are really complicated structures.

In general, too little has been done to establish the delicate details of the process of fossilization, largely owing to the fact that fossilization has been imagined to be quite simple, not requiring any special examination. This paper has as its aim to give some hints toward the actual examination of the detailed processes of plant fossilization in order to settle some of the cardinal points in the process of coal making.

Let us turn now to an analysis of different kinds of plant remains and some of the problems needing solution. First the plant remains should be classified according to their mode of preservation. Then the problems most needing examination should be reviewed.

MODE OF PLANT PRESERVATION.

There exist three principal ways or modes of plant preservation in the fossil state, as follows:

A. Phytoleims, or mummified plants. This form is produced when the original carbohydrates, their related materials, and their derivatives (cellulose, lignine, cutine, suberine, pectine, etc.) are partly or entirely altered into hydrocarbon, or rarely into carbon (graphite).

Isolated phytoleims sometimes preserve the shape and outline while only traces of the cellular structure are discernible, or they may have only the most delicate parts decayed, or in the case of subfossils, such as the Tertiary and Quaternary seeds, fruits, cones, wood, etc., they may retain the cellular structure quite intact. As components of coal or as lignitized stems and twigs, the phytoleims often retain their cellular structure perfectly preserved. Phytoleims, or mummified plants, usually are very easily interpreted, though it is

still not quite clear why some plant particles are fusainized while others are turned into vitrite or take the form of jet.

B. Petrified plants. This is a case in which the plant object is chemically altered or mineralized, being changed throughout into mineral matter, of any sort (silica, calcium or iron carbonate, limonite, etc.). The cellular structure in these cases is well or even perfectly preserved, often without any deformation of the plant tissues or the cell walls. The cell cavities are generally filled with mineral matter, mostly differing in color from that of the cell walls. There arise many questions concerning the state of the original cell walls, the means of their petrifaction, and the filling of the cavities, as well as concerning the starting point and the rapidity of the petrifaction.

C. Plant impressions and substitutions. Simple plant impressions may be formed where a plant or its parts have been included with the mineral deposits during sedimentation, or where they have been intruded subsequently, as in the case of roots growing into the sediment, or heavy fruits or seeds falling from a tree and embedding themselves in the sediment (*Rhizophora!*). In the case of true impressions only a negative cast of the object is left on the bedding plane or on random surfaces, in case the plant object was introduced after deposition or in case it was projecting up from the bottom so that the sediments settled around it.

PHYTOLEIMS.

As phytoleims (φυτόν — plant + λεῖμμα — remain) shall be considered all plant fossils, in which an original plant tissue or a plant organ whether of the nature of a carbohydrate or even of shells as in the case of the diatoms, skeletons of *Silicoflagellata*, or *Siphoneae verticillatae* are preserved with only slight alteration or a transformation of its material but without any exchange for mineral matter, that is, without any posthumous petrifaction or mineralization. Such phytoleims are commonly found as residua, only the most resistant parts being preserved. Examples are the famous Tovarkovo cuticles of the Moscow coal basin, or the cuticular sheaths of Devonian *Psilophyta* of Bazzas, Siberia (*Orestovia* sp., formerly described as *Himanthaliopsis*), which compose a peculiar kind of liptobiolite—the so-called tomite.

In these cases as well as in the recent discovery of wonderfully preserved Triassic plants (Prynada) in the Bogoslovsky Mine in the Urals, only a superficial layer of the plant body remains preserved in spite of the very considerable size of the remains—full size leaves of *Czekanowskia*, *Podozamites*, large parts of those of *Thinnfeldia*, thick shoots of *Orestovia*. The less resistant and at the same time more internal parts of the plants, including xylem and sclerenchym, are fully destroyed or changed into a dark structureless matter. To this group belong some of the "impressions" that follow the bedding planes and in which a coaly film is preserved. These are rather phytoleims than impressions in spite of the fact that some trace or impressions of the plant may also be left on the rock. In some cases more organic matter is left, as, for example, the veins of leaves in some Tertiary fossils, shells or crusts of some Quaternary, Tertiary, and even earlier nuts and other fruits and seeds, as well as spores, pollen grains, and other discernible remains in peat, brown coal, etc., where there may also be preserved some lignine, cellulose, and even resin, gummi, etc. In some instances massive phytoleims have their structure excellently preserved throughout. These are mostly the xylem of lignitized or anthracolithized stems, and some of these are of huge size (up to 2 meters in diameter at Chiderty, in Kazakhstan).

PETRIFACTIONS.

True petrifications are plant remains where the original carbonic plant matter is intimately replaced more or less posthumously by mineral matter and by a penetration of silica or carbonates into the interstitial tissue. Shells or skeletal remains, such as those of the diatoms, *Siphoneae verticillatae* and *Lithothamnia*, which result from the accumulation of mineral matter during the life processes of the plant and in which the mineral matter merely encrusts the outside of the plants without penetrating into the tissue and into the cell walls themselves are not petrifactions but encrustations and therefore belong rather with the "plant impressions," though having some peculiarities. Perhaps they should be referred to a special order of plant remains.

The most interesting problem is to determine what part of the original plant matter is usually left during petrifac-

tion, as in mineralized wood, coal balls, etc. Does the lignine, cellulose, or any of their derivatives remain inside the petrifaction, and can they be set free by some manipulation, or are those compounds replaced by mineral matter molecule by molecule? Actual observations along this line are quite scarce. Dr. M. Stopes once reported that after dissolving a block of petrified wood in hydrofluoric acid, she found a residue of soft organic matter. Neither microscopic examination of the matter nor chemical analysis was made and the experiment seems to be an isolated one. However, in the process of bleaching a polished surface of a coal ball or any other petrifaction, soft plant matter tends to be superficially freed from the mineral matter so that it can be transferred to the object glass for examination.

In order to establish the nature of the process of petrifaction (into silica, carbonate, etc.) it is necessary to carry on a series of experiments with solvents and a further study of the residua to be left. Such studies should be carried out on large blocks as well as on microscope slides. Operations with hydrofluoric acid which necessitate the use of paraffin or ebonite jars are rather cumbersome but nevertheless are easily manageable in any laboratory. After the mineral matter has been dissolved and traces of acid washed out, the plant residua should be studied under the microscope and in thin sections, and also analyzed chemically, to determine the composition and the state of the organic mass. This should also be studied by means of microchemical reactions.

PLANT IMPRESSIONS.

This is the widest field for investigation for the true nature of most of the varieties of this category of fossils is still scarcely known. Most of them actually represent not merely an impression but some very complicated combination of impressions with some other form of preservation, such as crustifications, phytoleims, internal molds, and partial petrifactions. It is necessary to distinguish in this category between the remains of flat objects such as leaves and scales, and those of massive ones such as fruits, seeds, blocks of wood, or entire stems, roots, petioles, etc.

A. Flat objects (mostly leaves). As the simplest case of this mode of preservation may be taken a leaf embedded on a layer of clay or shale and thus leaving impressions of both

its sides upon the respective planes of sedimentation of the rock. These impressions theoretically represent the lower and upper surfaces of the leaf and become visible when the rock is split open along the bedding plane. However, in order that these impressions may be seen, the original leaf or its phytoleim or coaly film must be entirely decayed and removed, leaving only a laminar cavity. Such impressions may be produced artificially by pressing some plastic material such as clay against a leaf or fern frond. Excellent impressions of this kind are produced by pressing a lead plate against a leaf or an entire herbarium specimen (the so-called "selbabdruck-process"). Using such a plate we can reproduce wonderful positive impressions of leaves with all their veins, exceeding the most perfect photographs. By such a process were reproduced the plates in the famous work of C. Ettingshausen, "Die Blattskelette der Dicotyledonen" (1861).

But undoubtedly such a simple way of making plant impressions is really quite rare. Usually when a specimen bearing a leaf is split along the latter, we can observe a coaly film more or less closely adhering to one surface, while the counterpart is free of any organic matter. Commonly this film can be easily removed, either entire or as a coaly powder by a needle or a brush. If the film is highly anthracolithized (graphitized), as in Carboniferous or older fossils, it can be removed by chemical means (Schultze solution, etc.). Furthermore, on the counterpart may be detected an impression of the side of the leaf opposite that represented on the first plate which was covered by a phytoleim. Therefore, actually only one piece of such a fossil can be regarded as an impression, while the other represents a phytoleim covering an impression. Finally, the two counterparts of "leaf impressions" really seldom represent the upper and lower surfaces of a leaf. Sometimes the laminar cavity, being left after decay of the plant matter, is filled with some mineral solutions, producing there a cast of the leaf.

Certainly simple mechanical leaf impressions are only rarely to be met. This is clearly proved by the fact that some leaves buried in coarse-grained sandstone produce on the rock excellent "impressions" where the minutest details are perfectly visible, although the sand grains are much larger than the details of the pattern reproduced and where we can sometimes discern under the microscope even the cell structures,

stomata, etc. The plant remains of the Paleocene and Eocene flora of the Ukraine, the Volga, and the South Urals are characterized by such preservation. On specimens of a grass, *Poacites bucephali* Krysht., from the Upper Cretaceous or the Tertiary of Turkestan there is distinctly shown the delicate superficial pattern of the leaves and leaf-sheaths, with the cell boundaries, stomata, and scales of silica.

One important fact shows further the unsatisfactory state of our knowledge concerning the true nature of plant remains usually considered as impressions. It is that, not uncommonly, the counterpart of an impression is not a coaly film or phytoleim nor the impression of the other side of the leaf but a negative impression of the same side. Such occurrences long ago attracted the attention of paleobotanists, and several witty explanations were advanced, among them one by the eminent French explorer, G. Saporta. He suggested that a leaf had settled on the bottom ooze or a wet surface of sediment and produced there an impression on the sediment, and that later it was blown away by the wind or carried away by current, and the impression of its under side was covered by a layer of sediment which thus formed a negative impression of the original under surface of the leaf. Certainly this explanation is too far-fetched for such a case to happen frequently.

Commonly, as on the sandy and ferruginous rocks—such as those of the Tertiary flora of the Aral region, Kazakhstan—the impressions are more or less differentiated from the rock itself by their coloring, having diverse tinges of pink, red, crimson, brown, buff, yellow, or olive color. Even if this color could be explained as due to the adsorption of matter by buried and decaying leaf, we can by no means attach to this phenomenon merely the coloring effect. Most naturally the delicate precipitate falling out of solution upon the object envelops the plant body and encrusts it, reproducing a negative cast of the object on the lower surface of the encrustation. This phenomenon can be observed on a more considerable scale in some roots, such as those of *Phragmites*, where it produces a hard tubular sheath which contains distinct impressions of the outer surface of the original object.

Some objects of plant origin represent a puzzle previously difficult to solve. They are called "demi-relief" or "halbseitiger Abguss" and represent, when the specimen is split open, on one surface of the rock an impression and on the other a counter-

part or negative of the same. When such an object is more or less massive, for instance a twig or a cone, we observe on one surface a concave impression (a negative of the object), while on the counterpart we see a positive repetition of the same. The peculiar feature of this case is that the convex impression is strictly one-sided, that is, we cannot trace the hinder side of the object by carving out the rock. It is a simple relief or a one-sided image, just a swell above the surface of the rock plate (*Brachyphyllum gracile* Brongn., from the Upper Jurassic of Cirin, France, as shown by Hirmer in 1927, Handbuch der Paläobotanik, p. 18, fig. 4; *Nymphaea dumasii* Sap., from the Oligocene of Alais, France, ibid., p. 12, fig. 3). A common explanation of such demi-relief is given as follows. It is suggested that the rock or solidified mud, with the fossil inside, is gradually washed away just to the surface of the concave impression. Then a new deposition of soft matter, ooze or silt, fills the cavity below and produces a demi-relief plant fossil. Certainly in this case the convex impression always should be on the hanging wall of the rock, and that is hardly the case. Some have suggested that after the decay of the plant object the hanging wall or covering layer of the rock was pressed down into the matrix already existing, but such interpretations, although rather ingenious, are too artificial and specialized to explain a common phenomenon. There are too many of these demi-relief fossils to admit the possibility of so many coincidences, and Doctor Hirmer is inclined to reject them, suggesting at the same time another possible origin, namely, that during life the calcareous film formed as a crust on one surface of the object. It is well known, for example, that a calcareous film sometimes envelops the leaves of *Potamogeton*, *Helodea*, and the lower surface of leaves of *Nymphaea*, etc. Doctor Hirmer attaches great importance to this idea but does not enter into any detail.

I shall try to give more natural explanations of the curious phenomenon and some intricate cases of leaf impressions, wherein we observe a negative impression of a leaf and the counterpart of the former or a positive of a leaf on the opposite surface of the specimen. It is well known that the dead or fallen leaves, twigs, fruits, etc., resting and slowly decaying in the hard or muddy water of lakes and pools, or even of streams, are soon enveloped by a thin film that is at first easily removed by rubbing with a finger. The decomposition

of the plant matter and the emission of CO_2 and other gases, causes chemical precipitation and makes the clay particles coagulate on the surface of the plant. In this precipitation iron carbonate and calcium carbonate play an important rôle. Being deposited on the leaf surface, or upon any surface of any plant object, this precipitation produces a thin crust reproducing the finest detail of the surface pattern of the object. The details surely are reproduced negatively on the inner or lower side of the crust deposited, but during the initial stage when this film is still very thin, these features are equally but positively reproduced on the upper surface of the crust, just as such details could be reproduced by the galvanoplastic process. Therefore, I propose to call this process of fossilization *petroplastic*, and the delicate film, a *primary* or *initial crust*. If this crust grows thicker, its lower surface preserves its primordial condition, while upon the outer surface the features of the object beneath gradually are obliterated as the crust grows. These final stages we can observe in travertines where minute plant particles, are wholly enveloped with a thick crust bordering a cavity as a remnant of the former vegetable object which had been destroyed long before the travertine was finally made. Of course this cavity may be filled again with calcareous deposition from the circulating solution, but usually such a process is not accomplished, because inside the cavity there remains no focus which could cause the precipitation. It is quite possible that during this process of encrustation the mineral matter somewhat penetrates into the upper layer of a leaf or other plant object, partly petrifying it. When split open, such a specimen discloses a negative impression upon one plate of rock and a positive on the counterpart. The latter one is represented either by an upper surface of the film in question or by a petrified surface of the leaf itself. The negative impression then could be made either by sediment upon the upper surface of the crust or by the lower surface of the crust itself, depending upon the position in which the split has passed.

In some Tertiary sandstones of the Ukraine, the Volga region, and the Urals, we can easily observe that small plant particles buried in the quartz sandstone are really petrified as thin branches, petioles, small thick leaves, etc., as is proved by making thin slides of the rock (Paleocene of Smolino Lake near Cheliabinsk, Siberia). Accepting such a method of

making some leaf "impressions," we can easily explain many difficulties unavoidable under any other theory. However, it is quite certain that in this process different sides of a leaf behave differently. For instance, if the leaf was flatly lying upon the mud or the sandy bottom of a basin, even being partly embedded in the mud, the lower surface of the leaf behaves differently and is more intimately fused with the substratum, not producing any clear impression on and not giving place to a crust-making. The crust, on the contrary, is formed on the open or upper surface of the leaf.

In order to prove decidedly the validity of this process and the existence of the mineral film, and possibly an intimate superficial mineralization of the object, it is necessary to carry out some actual investigations of different types of plant remains by making transverse thin sections, chemical analyses, etc., as well as by intimate studies of the minute pattern and the relief of such objects, as, for example, the live leaves of *Quercus*, *Laurus*, *Cinnamonium*, etc., for a comparison with the relief of the fossil specimens. Special attention should be paid to the examination of the first stages of making mineral or muddy crusts upon the plant debris decaying in stagnant water. The same processes are responsible for producing casts or impressions of bulky or massive objects of plant origin as is shown below.

B. Massive objects. When a massive plant object is included in muddy sediment, which later on turns into rock, and if the plant turns into coal or is petrified without any considerable change in original size, then on the adhering surface of the enclosing rock there is reproduced an exact impression of the external surface of the object, a purely mechanical mold in the simplest cases. If the object happens to have a cavity easily accessible for penetration by the mud and sand either during life or post mortem, such as the hollows of the stems of *Calamites*, the inner space of a nut, etc., it becomes filled with the same mud or sand, and the filling (core) does not differ afterwards in its color from the surrounding rock.

When the matrix and the core are solidified, the object itself may degenerate into an insignificant coaly remnant or may be destroyed altogether, leaving just a cavity in the rock instead of the former plant object. If the rock is not plastic, the cavity may remain open indefinitely, otherwise it may be filled gradually with some mineral mass (calcite, chalcedony,

opal, quartz, etc.), making a cast or a core of the inner cavity without any cell structure. Sometimes on the wall of such a cast there is a thin coaly film but its thickness in no way corresponds to the original object. Otherwise the object may not decay but be preserved in a petrified condition with all of its form. These conditions are quite simple to understand. Much more intricate are the cases when a massive object is completely replaced in the same rock which surrounds the specimen (mud, silt, or sand), sometimes with a coaly film or a mineral crust representing a thin, really petrified layer of the object itself.

Though it is quite easy to suggest how the sediments enter into a cavity, it is very difficult to imagine how a massive object being included in the half-liquid or viscous mud could be replaced by a surrounding mass without a decrease or with a slight change of its volume and shape, producing at the same time an impression of its surface on the embedded rock. It is necessary to point out that on the sea or lake bottom the mud particles are especially apt to penetrate through infinitely small interstices and to fill, in this manner, all cavities in the object buried on the bottom.

It is well known that all compartments of wrecked vessels lying on the sea bottom are completely filled with mud, which always has to be removed before the raising of the ship. Even such a tightly closed device as a watch, after a couple of years in the bottom mud, will be filled with the finest mud. This penetration of the mud particles into the object is especially aided when some processes of decay are going on. The convection currents which arise in these conditions produce permanent circulation of the finest suspended particles and assist their penetration inside the body in question by any possible channel. Each fissure becomes instantly filled with ooze, which moves farther inside just as the cell walls or such tissues as medullary parenchyma are more or less disorganized and give way to the mud particles. In this way the plant body, having produced at the beginning of the burying process its external impression, becomes more or less substituted by minute particles of mineral partly chemically deposited. It is certain that some parts of the plant mass may undergo true petrifaction. In order to establish this process, such substitutions should be thoroughly investigated under the microscope as in thin slides. We should not expect to discover there any well-preserved tissues but

surely some trace of cellular structure should be discovered, if some portions of the original body have undergone direct mineralization. Thus, some traces of cells were reported even in such early objects as the Proterozoic algae *Newlandia* and *Camasia* (Knowlton, Plants of the Past, pp. 41–43).

One peculiar feature should be pointed out in the specimens preserved as rock substitution. It is a coaly or mineral film just on the boundary of the including rock and the buried object, very often being preserved as a demi-relief not separated sharply in its base from the enclosing rock. It is very remarkable that in these cases only a very thin coaly or siliceous film remains of the massive stems of conifers and calamites, while the remaining or inner part of the plant body, often more or less considerably flattened, is replaced by rock particles as an entire isolated specimen or as a demi-relief fused at the base with the enclosing rock. It is evident that the most superficial layer of the object (being a stem, a fruit, or a seed), which stands in immediate contact with the outer medium, rapidly undergoes some petrifaction, turning into a siliceous film, or suffers anthracolithization, while the inner parts of the plant body are subjected to further and even final decomposition in a more anaerobic condition, during which process the body is gradually replaced by the surrounding rock, which intrudes into all the weak portions along the channels of slight resistance. If the lower surface or the base of the object is immersed into a mud, the decomposition process catches there also the superficial layer, destroying in this way the boundary between the object and the embedded rock or ooze. By these means an origin of a true demi-relief is easily comprehensible. The making of coaly or mineral film depends on different conditions.

In such substitutions and demi-relief formations, there is also observed a considerable change in the shape and the volume of the original plant body, though sometimes they undergo no alteration (this case is to be discussed below and depends chiefly upon the kind of pressure within the rock or sediment, which can be either one-sided or hydrostatic). After fossilization, trunks or limbs of trees often become quite flattened, with a coaly or mineral crust (mostly siliceous) around them or upon one side (the upper one?), with rough traces of the woody fabric, such as annual rings, medullary rays, etc., upon the surfaces that were split open before the object was buried in the sediment.

Some observations could give hints as to the processes undergone in these cases. For example, if the coaly film upon the substituted specimen belongs to an equisetacean, it is evident that only the more resistant tissues were preserved, such as the cuticular surface layer or the thin-walled xylem cylinder, while other tissues were undoubtedly destroyed. However, when we deal with a massive trunk of cordite or a coniferous tree, where the whole mass of the woody cylinder was equally solid, the preservation of a thin superficial coaly layer could not be attributed to the properties of the tissue itself but must be due to the intricate method of fossilization in which the outer layers have undergone an influence different from that of the inner parts. In some instances this process resulted in petrifaction of the superficial layer, and in others it reduced it to a carbonized condition.

CHANGE IN THE SHAPE AND VOLUME OF FOSSIL PLANT OBJECTS.

It is easy to note that massive plant bodies, whether preserved as phytoleims or replacements or even just cavities, show great variation with respect to the degree to which they retain their original size and shape. Some of them preserve perfectly the original shape and dimensions, while others are considerably flattened, compressed, or otherwise changed. It is remarkable that some cylindrical, globular, or ellipsoidal cavities left in the rock by decomposed roots, shoots, or fruits (as in the Paleogene sands of the Ukraine), very often remain quite intact and hollow in a quartz-like sandstone which surely was at one time buried to a considerable depth, while similar objects in other places, in sandstone or shale, are variously deformed, compressed, flattened, or even turned into a thin crust or a film. Such deformation and flattening is usually observed even though the object has been buried to insignificant depth below the surface in recent peat bogs.

A plant body such as a piece of trunk, or a fruit, soaked with water and submerged to the bottom or into the bottom ooze, does not endure any stress pressure but only the hydrostatic pressure on the outside which is balanced by the inner pressure in the object impregnated with water. Therefore, until conditions are changed, there is no reason why the object should change its shape even if it were covered by a bed of sediment. If the bed or the rock later on loses its water while the particles remain loose and mobile, the condition is changed

and there arises vertical or stress pressure having a tendency to compress or flatten the object, which process is alleviated by the loss of some of the volatile matter of the object.

However, if the sediment turning into rock is cemented at an early stage it loses its plasticity at moderate pressure, the plant remains, or even a cavity left after its decomposition will remain intact. The cavities remain open, especially in quartz sandstone, where the plant debris was buried partly under aeolian conditions and where the sand soon became solidified under the influence of a hot or warm climate with alternations of dry and wet seasons. A cavity in this case can be followed by some precipitation of mineral matter producing a core or a cast. Such cavities could arise epigenetically in the rocks by means of the envelopment of growing roots, which have a strong sheath, and preserving on its inner surface minute details of the surface pattern of the former plant remains which is soon decomposed. Otherwise, if the plant object remains, it can form either a phytoleim or a petrifaction.

If the rock remains more or less plastic, giving up its water, it puts the plant inclusion under stress pressure, whereby the latter easily gives way and is deformed, while the more resistant petrified objects preserve their shape without alteration unless influenced later by more vigorous tectonic movements.

Sometimes the plant remnant passes successively through several transformations of different character, due to change in environment and the operating forces. Several processes of fossilization can act upon a massive object either at the same time or in successive stages during a lapse of time. We know several cases wherein the outer layer of a trunk was turned into bright coal while the inner part was quite silicified (the Mesozoic of the Far East).

These wonderful phenomena till now had not attracted sufficient attention and had not been studied enough in order to develop the causes of these various types of fossilization through making clear the processes which will shed light upon the destiny of the different plant tissues during fossilization and will accelerate solving the problem of the mother substance of coal.

Truly these investigations are very complicated and necessitate many studies with intricate techniques, where a botanist, a bacteriologist, and a chemist should join in detailed studies of the living, the dead, and fossilized plant stuff in various

states and in diverse conditions. However, these investigations are quite worth carrying on on a considerable scale, for their results are no less promising than the well-known work of Marie Stopes (1919) on the four coal ingredients, done during the coal shortage of the first World War, when responsible circles were desperately struggling for the most economic ways of dealing with coal.

Naturally the solving of the problem concerns not only the coals but all kinds of caustobiolites—among them petroleum.

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LIMULOID TRAILS FROM THE UPPER TRIASSIC (CHINLE) OF THE PETRIFIED FOREST NATIONAL MONUMENT, ARIZONA.

KENNETH E. CASTER.

ABSTRACT. The Newspaper Rock ("Pictograph") sandstone (Chinle: Upper Triassic) of the Petrified Forest National Monument, Arizona, yields a new type of limuloid trail (*Kouphichnium arizonae* Caster, new form) which is interesting for the perfection of the xiphosurous track detail; for exhibiting in the holotype trail two variations of the ectognath imprint, either of which in the past would have been the basis for correlating the trail with a bipedal vertebrate; and finally, for establishing quite certainly the direction in which the track-maker progressed,—a matter of previous divergent opinion. The presence of the Xiphosura in the Chinle poses ecologic problems not hitherto considered in evaluating these purportedly wholly continental deposits.

INTRODUCTION.

HETEROPOD trails are known from the record of nearly half a billion years (Cambrian to Recent), and are troublesome Problematica always. In recent years we have grown sufficiently familiar with the ichnology of existing organisms somewhat more satisfactorily to tackle the solution. The new Upper Triassic trails herein described are important evidence for the xiphosuran interpretation of one type of very ancient heteropod trail. These spoor are at the same time a synthesis of three kinds of track evidence, each of which in other years would probably have been evaluated as attributable to the Vertebrata. In fact, the new trails had been informally identified in this manner when first seen by the writer.

Mr. Howard Stagner, Park Naturalist (1939) at the Petrified Forest National Monument, called our attention to the trails on exhibition with Triassic vertebrate material in the Monument Museum. Through Mr. Stagner's kindness and coöperation, permission was secured from the National Park Service to borrow the trails for study in Cincinnati. He also generously provided stratigraphic data and searched with some success for additional materials. Stagner's description of the stratigraphy of the Newspaper Rock sandstone appears under his name in Daugherty's (1941) monograph on the Upper Triassic Flora of Arizona.

HETEROPOD TRAILS.

In order to present the clarifying data to be gleaned from the new Triassic trails, it seems advisable first briefly to summarize our knowledge of this general type of trail. Although formerly assigned to vertebrates, in the last few years trails such as this have been more successfully correlated with king crabs. The belated solution of the Problematica is due to the great variability of limulid trails, on the one hand, and general ignorance of their ichnology, on the other. Probably no organisms capable of making a trail of more than one kind of footprints, makes more mutable and misleading records than the Limulida. Their perplexing register goes back to early Paleozoic times, and out of it has grown a truly amazing lore.

In those few instances where limulid cadavers occur in the same beds as the trails, (*e.g.*, the remains of *Protolimulus* Williams (1885) and Packard's (1900) *Merostomichnites* trails occur together in the Upper Devonian of the Penn-York Embayment), or at the end of a "death-march" after the manner of the common occurrence of *Limulus walchi* in the Solnhofen Jurassic (Walther, 1904), the spoor have been, almost inescapably, rightly correlated. But, curiously, because such trails were accepted as limulid on the *prima facie* evidence of association, they were seldom, if ever, until recently, closely analyzed. Consequently, a surprising number of trails virtually identical to those associated with remains, but without direct carcass connection, have been interpreted, on the basis of first impression, and often with great pains and ingenuity, as vestiges of vertebrates.

Briefly to pursue this curious oversight with a few examples,—we find thousands of tracks and trails in the Solnhofen Plattenkalke all showing the same details as those which lead to dead crabs; yet, for three-quarters of a century these have been known under the name *Kouphichnium* (Oppel, 1862) and in all that time on only one occasion has a single specimen of the trails been correlated with the crab that made it (Abel, 1935). Even this trail, which preserves the very outline of the carapace, was relegated for half a century to the vertebrates! *Kouphichnium* has through the years been attributed by a long list of most eminent paleontologists to pterodactyls, bipedal dinosaurs, ancient birds and jumping mammals. Jaekel (1929) divided the Solnhofen spoor into four groupings, all of which he

thought were made either by *Archaeopteryx* and *Archaeornis* or by three still more ancient and otherwise unknown "Urvogel". The *Limulus* features of these trails are so patent, when once those feature are understood, that it was really a very simple matter to make the necessary comparisons for establishing their relationship with the ubiquitous *Limulus walchi* of the Solnhofen deposits. It is more understandable that certain other limuloid trails, which occur in strata devoid of crab remains thus far, were at first misconstrued as evidence of tetrapods. The Upper Devonian trails in the Catskill beds of Pennsylvania, which Willard (1935) described as *Paramphibius*, are of this ilk. The hypothetical track-maker of the Devonian made a rather plausible bridge between the fishes and the amphibians ("Ichthyopoda") until the merostome possibilities of its spoor were investigated. The Triassic trails from New Jersey which Abel (1926, 1935) called *Micrichnus* and *Artiodactylus*, perfectly typical limulid trails though they are, still offer fewer ecological difficulties when interpreted as birds, dinosaurs or split-clawed mammals, than they do, as what they are.

The principal reason for the error in evaluating limulid trails is the curious toed aspect of the imprints made by the fifth pair of walking legs (ectognaths). The basic plan of *Limulus* ichnology has been generalized in a previous paper by the writer (1938, Fig. 5). In essence, the walking-trail comprises forwardly-directed chevrons of round holes or bifid imprints or scratches made by the anterior three or four pairs of simple supporting feet (endognaths). The endognathic chevrons are in alternation with the imprints of the fifth pair of feet (ectognaths) which are modified by four or five movable blades at the termination of the antepenult segment for the function of pushing the animal forward. See Text Fig. 1. Since the anterior four pairs of feet act more or less as a unit in alternation with the pushers, a sort of tetrapodal gait is achieved by the limulids, and heteropody characterizes the trail.

The pusher has undergone minor evolutionary changes since it first appeared in the middle Paleozoic; there is also considerable ontogenetic modification of the organ which correlates rather well with the paleontologic changes (see Caster, 1938, Fig. 4). In addition to these biogenetic possibilities of variation, there is considerable variation in employment of the device at all stages. No matter what the variant, its track most strik-

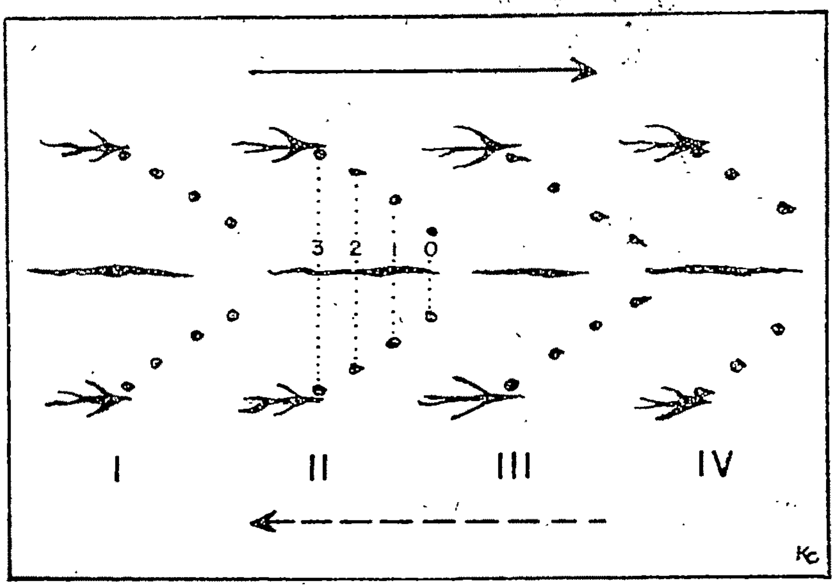

Fig. 1. Diagram of an adult *Limulus* trail. This illustrates the contrast between reality and the vertebrate hypothesis[1] usually offered to account for such spoor. Solid arrow points the direction in which the crab walked; dash-line arrow shows the orientation necessary for the vertebrate interpretation. I-IV, successive steps or hitches of the king crab; 0-3, imprints of the four anterior pairs of simple feet (endognaths); the first pair (0) are seldom recorded; 4, tracks of the fifth pair of feet (ectognaths) or pushers. Figure 2 demonstrates the variations in ectognathic function and tracks. An analysis of *Limulus* locomotion is given as Fig. 5 in the writer's 1938 paper.

[1] In contrast to the limulid analysis of such a trail, we have the various vertebrate theories, all of which are perhaps epitomized by that of Wilfarth (1937). He accounted for the very similar *Kouphichnium* trail in the Solnhofen Jurassic as follows: first, after a careful survey of vertebrate possibilities, he "imported" the American bipedal dinosaur, *Ornitholestes*, the only vertebrate known to him, as he said, precisely capable of making the trail. He imagined that the little dinosaur hobbled along by "trial and error"; sitting on its haunches at track III, it reached forward to position *1* with its short dangling fore-feet and pressed its longest digits in the mud; this was apparently not far enough; it then lifted its arms, and spreading them a little further apart, implanted them further forward at position *2*; still not far enough; for a third time, it reached forward, with wider spreading arms, to implant its middle digits at station *3*; only after this preliminary exploration did the dinosaur move forward by the wholly ingenuous device of using its implanted fore-feet and longest fingers in the manner of "crutches" by which to swing its hind-feet "through its arm-pits," thus to stand at last at the new position II; whereupon, the "trial and error" skirmish was renewed before the next "jump" was made!

ingly simulates the hind-foot print of a vertebrate. Some of the best-known variations in the flabellar (pusher) imprint are shown, together with their mode of origin, in Text Fig. 2. As

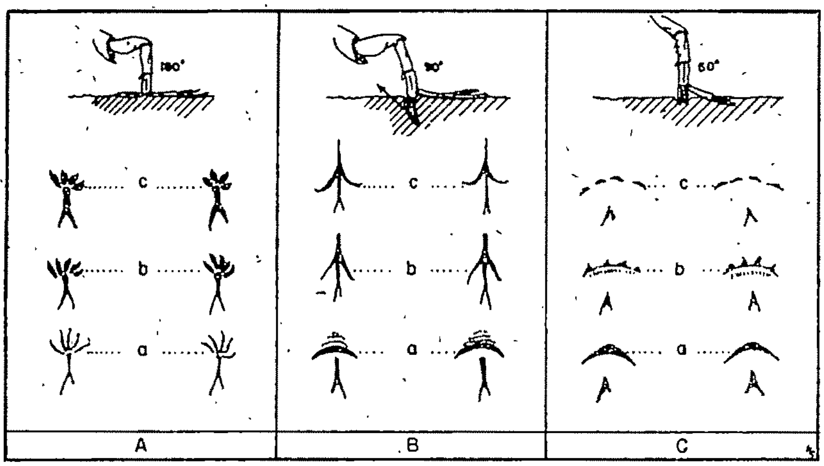

Fig. 2. Vertebrate-like tracks made by the pusher (flabellum) of the Xiphosura. In all examples the crabs walked up the page. A. Immature and ancestral Xiphosura; tracks made by a flatly impressed five-bladed flabellum which was fully expanded; the fan makes an 180° with the underbent ectognath segments; *a*, *Paramphibius* condition in the Upper Devonian; first interpreted as a fish-amphibian ("Ichthyopod"); *b*, four or five-bladed pusher, likewise flatly imprinted; Permian tracks of this type have been interpreted as the earliest bird tracks, and the rather similar *Artiodactylus* of the Triassic was interpreted as either mammal or reptile; *c*, immature flabellar imprint of a modern king crab; very similar to certain aspects of *Kouphichnium* of the Jurassic. B. Variations in the adult imprints of the limulid flabellum, the pusher being in these examples completely inserted in the mud during the forward push; the blades make an angle of only 90°, or a little less, with the distal ectognath segments. *a*, vertically inserted blades; distal segments flat on the ground; some forward drag and distortion of the bottom upon withdrawal of the blades preparatory to the next step; *Micrichnus* from the Triassic and variations of *Kouphichnium* in the Jurassic are of this type; both were formerly interpreted as vertebrate spoor; this type of track is commonly seen on modern beaches and very well shown in *Micrichnus paleocenus* Russell (1940) from the Paskapoo Paleocene of Alberta; *b*, similarly inserted blade, but the semicircle of blades becoming forwardly concave to form a chevron-shape insertion; considerable forward gouge formed at time of withdrawal; described as reptile and bird tracks from the Triassic and Jurassic; correctly identified in the Paleocene; *c*, still greater flexibility of the arc of the pusher to form chevrons of inverted quarter-circles; common today; described as ancient bird tracks (*Ornichnites* and *Protornis*) in the Solnhofen Jurassic. This is the flabellar condition to be seen on the left side of the holotype of the new Triassic trail. C. Incomplete semicircular imprints of flabellum; variants of B, *a*; blades make less than 90° angle

the legend of this figure indicates, many of these flabellar mutations have been the basis for form-genera and species. Since in most instances the ichnological categories correlate with morphologic differences of the known or unknown track-maker, they are in a sense justified, and are often very useful. The flabellum originally contained five blades, but there has been a recurring tendency to lose one, thus changing the aspect from an asymmetrical semicircle, to a bipartite arrangement of parts. The angle made by the blades and the underbent terminal segments of the pushing leg decreases both paleontologically and ontogenetically; the amount of lateral or fanwise spread of the blades is another variable matter.

Certain of the flabellar imprints create a tetrapod illusion when oriented in the limulid manner, as seen in Text Fig. 2, A and C, whilst others have such an aspect only when viewed in a contrary manner, as for example, Text Fig. 2, B. Since any adult *Limulus* or limulid can make both sorts of tracks at will, possibly with certain ecologic contingencies as determinants, and since these tracks are so very different in appearance, it is not surprising to find two form-genera of supposedly vertebrate ichnites in several of the limulid track localities. Text Fig. 2 illustrates many of these features and cites examples.

In the holotype slab of the new trail from the Arizona Triassic, we find the interesting association of both types of trails in a single record. The right and left sides of this trail, if not associated as we see them here, would have been almost certainly assigned in former times to two different form-genera and species of vertebrate. Furthermore, the two genera would have been imagined to have walked in opposite directions. In other words, according to the seventy-five-year-old ichnological custom, the right side of the trail would have been viewed as made by an animal walking up Plate 1, whereas the left side

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with underbent terminal segments and are incompletely inserted so as to make a disjunct track; *a*, common condition today in rather soft mud; *b*, broadly expanded blades; after insertion the backward push distorts the mud so as to simulate a sole-print of a vertebrate; terminal spine prints often obscure in this type of track; such tracks have been interpreted as mammalian; this is the condition to be seen on the right side of the new Triassic trail, plate 1; *c*, "tip-toe" track made by the vertically imbedded blades and the tip of ectognath; a somewhat rarer modern track; also known from the Newark Series and the Solnhofen beds.

corresponds to a hypothetical animal walking down the page! By the accident of uniting both sorts of perfectly normal adult *Limulus* tracks in one trail this holotype becomes a sort of minor "Rosetta stone" in heteropod ichnology. There is no question of the limulid origin of the new trail, and it differs only in minor features from the famous *Kouphichnium* trails of *Limulus walchi* in the Jurassic. Those minor features seem adequate, in view of the years separating the records, to warrant a separate specific name for the Arizona trail.

Kouphichnium arizonae Caster, new form.

Plate 1

All details of this new trail are to be seen on the original and best (holotype) example of the spoor which is illustrated on Plate 1. This specimen is on exhibition in the Museum of the Petrified Forest National Monument, near Holbrook, Arizona. A rubber mold of the holotype slab is in the University of Cincinnati type collection (No. 24300), and plaster molds will be gladly furnished those who are interested.

The type sandstone trail shows on either side of a nearly continuous middle groove (telson drag-mark) six serial imprints of three pairs of endognathic limulid feet and five serial repetitions of the ectognathic pushers. The average width of the trail is 65 mm. and of the endognathic portion only, about 35 mm. The braces of tracks are about 35 mm. apart. The endognath imprints apparently correspond to tracks 1-3 of Text. Fig. 1; the ectognathic ones correspond to No. 4 in that figure. At the place marked "g" on the photograph, a single

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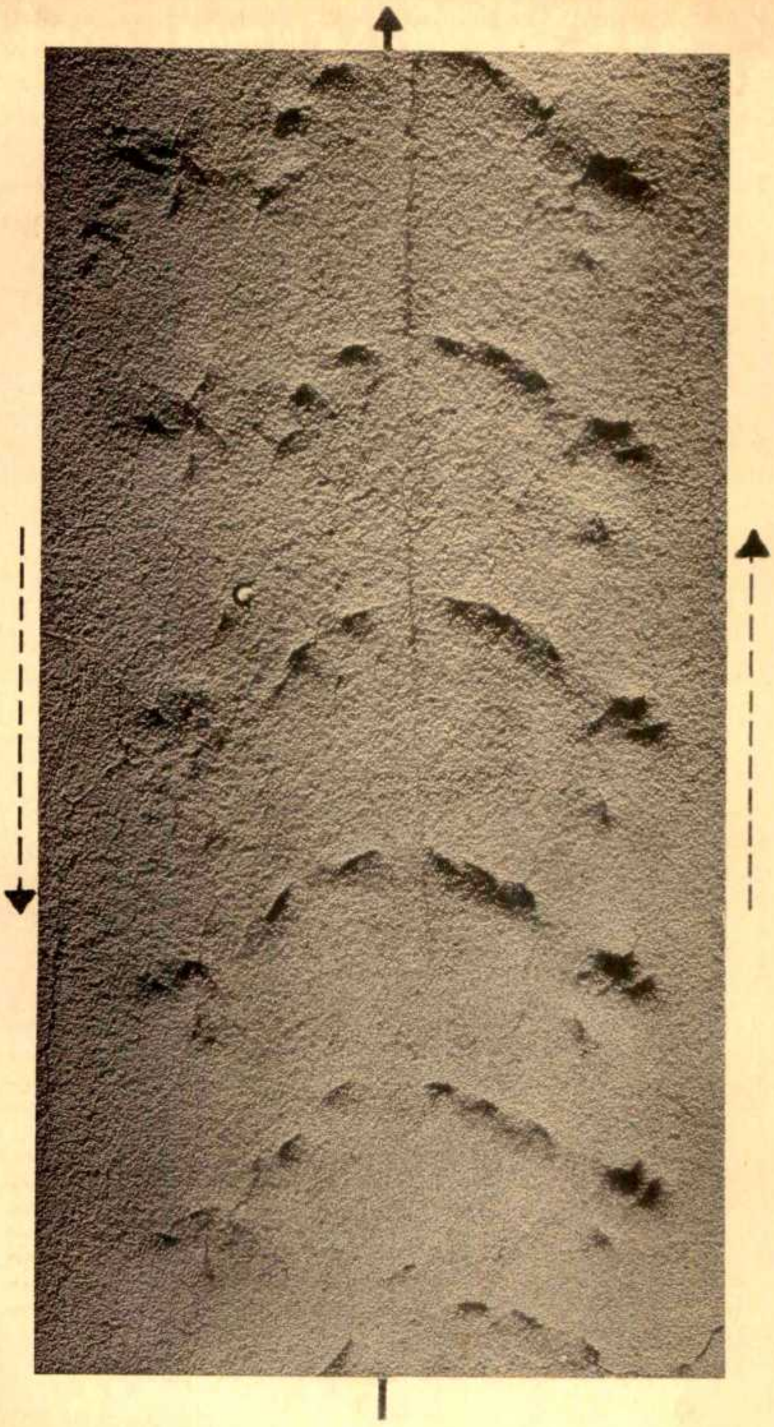
Plate 1

Kouphichnium arizonae Caster, new form. A *Limulus* trail from the Upper Triassic of Arizona: Newspaper rock ("Pictograph") sandstone member of the Chinle terrane. This holotype slab came from the Blue Forest area of the Petrified Forest National Monument, near Holbrook, Arizona. Type specimen in the Petrified Forest Museum. × 1.

Compare with the track diagram given as Text Figs. 1 and 2; as will be seen, the crab walked up the page, as indicated by the central solid arrow; the dash-line arrows indicate directions in which the hypothetical vertebrates have been assumed to walk in order to account for tracks such as seen on either the left or right side of the trail. The crab apparently careened to the left while walking diagonally up a sloping sand surface. *G* indicates a gouge made by the left cephalic spine during the precarious climb up the slope.



gouge mark is shown; this apparently corresponds to the occasional mark left by the genal-spines of modern *Limulus.* (See Caster, 1938). The chevrons of simple tracks are unusual in being mere slits, rather than the usual oval or bifid ectognath imprints. This apparently reflects backward and lateral pushing or scratching with the simple feet and may correlate with the strenuous work of walking up a sloping beach. By forcing horseshoe crabs to walk up a sloping mud surface, somewhat comparable trails have been made experimentally. None of the Triassic trails show the bifid nature of the endognaths, but this is not unusual.

As we have already anticipated, the pusher tracks of the holotype slab are unique in their asymmetry. The tracks on the left side are normal for an adult walking crab. The condition is that shown diagrammatically in Text Fig. 2 *B, c.* The ones on the right are ordinarily made by a half-walking, half-swimming crab, since they are what might be termed "tiptoe" tracks which record only part of the flabellar anatomy. In this case the animal was apparently having a difficult passage up the sloping wet sand beach, and apparently proceeded careening toward the left side, thus to leave the occasional record of its left cheek-spine, and always barely able to keep its right pusher functioning. The strand-line probably was parallel to a diagonal from the upper left to the lower right of the picture; the slope to the lower left.

If the trail were symmetrical, with either type of pusher track duplicated to the exclusion of the other, the result would be very much like the Jurassic *Kouphichnium.* In the new trail the chevons of simple imprints are much more obtuse than in the Jurassic ichnite. The "jump" of the Triassic crab is slightly greater than in the Jurassic one, and the flabellar legs were apparently somewhat longer, for the pusher tracks are not superimposed upon the simple chevrons as they usually are in the Jurassic. It is doubtful if more than three of the Jurassic simple feet ever left their imprint, whereas here we see the regular record of four. Of the various mutations of the Solnhofen trail, those termed *Ornichnites caudatum* by Jaekel (1929) show ectognath records most similar to the left side of the present one. Somewhat similar trails have been described by Russell (1940) from the Paskapoo Paleocene of Alberta under the name *Micrichnus paleocenus,* and recognized as limulid trails. Russell was wisely reluctant to propose a new form-

genus for his ichnites, and consequently referred them to Abel's Triassic form-genus, apparently not knowing of the true nature of the much more similar Jurassic *Kouphichnium*, to which the trails could with greater felicity be referred. The points of difference between the new Triassic trails and those from the Paskapoo are in details of the flabellar print, as can be seen by reference to Text Fig. 2 B, *a*, and the sparsity of endognathic imprints in the Paleocene trails. Most of the few simple imprints recorded show the bifid nature of the feet. Probably there was really very little change in the foot plan of the Limulids from Chinle to Paskapoo time, although there were undoubtedly carapace changes of specific importance; however, those characters are yet to be discovered in both terranes.

The only Triassic trails known to be limulid are those previously mentioned in the Newark series of New Jersey, of approximately the same age as the new ones. Both the *Micrichnus* and *Artiodactylus* forms of the Newark trails are much smaller and apparently reflect smaller adult crabs. They bear fewer simple imprints in alternation with the flabellar prints, and frequently show the terminal spines of the simple feet. The nature of the flabellar prints of the Newark crabs is shown in Fig. 2. We seem to be dealing with clues to two distinct species of limulid in the North American Trias. Both need to be verified by actual remains.

Occurrence.—According to data supplied by Mr. Howard Stagner, the new trails occur only in the "Pictograph" (Newspaper Rock, Stagner, 1941) sandstone member of the Upper Triassic, Chinle terrane, in the Blue Forest area of the Petrified Forest National Monument, near Holbrook, Arizona. This is in Sec. 22, T. 18 N., R. 24 E. of the Petrified Forest topographic quadrangle map. The sandstone interfingers with the shale from which Daugherty (1941) secured most of the excellent leaf imprints for his monograph. The sandstone is somewhat cross-bedded, and the tracks apparently occur on sloping foresets. Other tracks, none of which are comparable, and some of which are apparently of vertebrate origin, occur in the Newspaper Rock layer.

The Triassic setting of the Chinle sandstone terrane appears to have been formed on a plains area not far removed from the Triassic embayment of the sea. The flora described by Daugherty (1941) and the vertebrates described by Camp (1930) seemingly indicate the same general setting which Camp

described as follows: "The Chinle was presumably deposited on a great low-lying floodplain near the seacoast, traversed by slow-moving streams subject to occasional overflows and freshets, and interspersed with large swampy areas and shallow lakes with scattered stands of conifers on the higher ground." With this picture of a low-lying coastal plain it is not difficult to think of the track-layers as a strand deposit on a dissected coast, perhaps merely a deposit formed in a deep embayment, or possibly during a temporary submergence of the coastal area. We need not even postulate wholly marine conditions, since crabs can live for long periods if subjected by urge or accident to brackish or even fresh water.[2]

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[2] There will be those who urge that this new record is added proof of the erstwhile fresh water invasion of certain members of the Limulida. Russell (1941) suggested this possibility to account for the limulid trails in the Paleocene Paskapoo some 800 miles from the nearest known occurrence of the marine Paleocene (Midway: Cannonball). The *Micrichnus* and *Artiodactylus* trails of the Newark terrane of New Jersey likewise occur in beds always judged to be wholly continental, intermontane deposits. Bucher (1940) was prone to consider favorably an argument posed by the writer (1940) that the "continent" of Appalachia may have been very tenuous in Upper Triassic times and that the deeper Atlantic estuaries may have penetrated the "intermontane" region thus opening the mud-flats to the nuptial conquest of limulids. It is unfortunate that our knowledge of Paleocene paleogeography is so meager as yet that we cannot in truth say how close the Paskapoo site really lay to the Midway embayment. There may be subsurface marine equivalents of the Paskapoo beds much nearer than the 800 miles cited by Russell to the nearest outcrop. The physiographic setting of the Paskapoo locale in Paleocene time was apparently in many respects similar to that of the Chinle of Arizona in the Upper Trias. It would seem premature, at this state of knowledge, to postulate, from uncertain ecological data alone, that any of the Limulida ever lived their course in a setting wherein never a single carcass has yet been found; their skeletal record is wholly marine.

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THE SEDIMENTS OF FOUR WOODLAND LAKES, VILAS COUNTY, WISCONSIN.

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PART II.

MUSKELLUNGE LAKE AND ITS SEDIMENTS.

Muskellunge Lake has an area slightly exceeding 900 acres (919 acres) (Fig. 6). It has no definite outlet and only a few small inlets. The lake occupies a pit, or probably several connected pits, in a glacial outwash deposit. There are three small islands in the southwestern part of the lake and a long peninsula which is almost an island on the east end. The general shape is that of a crescent open to the southeast. The maximum depth is 20.7 meters. This is found in a hole in the central part of the basin. The shore line has an approximate length of eight miles. The lake is almost entirely surrounded by second growth forest. Its relation to other lakes considered in this paper are shown in Fig. 1.

The waters in Muskellunge Lake are soft and probably generally oligotrophic. The pH has the approximate value of 7.3 in the surface waters. It is somewhat less with depth. The bound carbon dioxide is 10 parts per million, the bound calcium 6.3 parts per million, and the bound magnesium 2 parts per million. There is a small increase of calcium with depth. The content of silica on August 25, 1932, ranged from 0.6 parts per million in the surface waters to 1.0 part per million at the depth of 19 meters; oxygen ranged from 8.0 parts per million in the surface waters to 0.2 part per million at the depth of 19 meters and carbon dioxide from 1.0 part per million in the surface waters to 21.5 parts per million at the depth of 19 meters. Ferrous and ferric iron ranged respectively from nothing in the surface waters to 0.8 and 0.0 at the depth of 19 meters (Juday, Birge, and Meloche, 1938).

Ekman samples were collected in Muskellunge Lake from 129 stations in 13 ranges (Fig. 6). Depending on position, the samples consist of sands and gyttja. The area enclosed by the dashed line of figure indicates the parts of the bottom over which the sediments consist of black to greenish or brownish

gray gyttja. No chemical analyses were made of the samples of gyttja as they seem to be similar to other gyttja sediments of the lakes of the region. There sediments are known to consist of more than 90 per cent water, and to have 50 or more

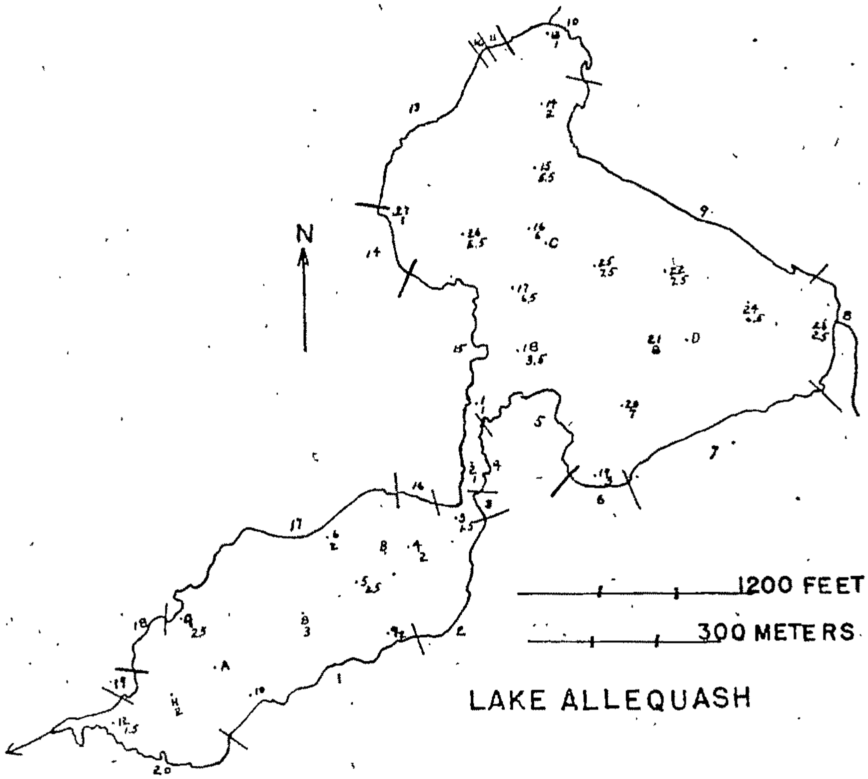

Fig. 6. Muskellunge Lake. The upper figure of the pairs represent the numbers of the station. The lower figure of the pairs, the depth at the station. A topographic map has been made of the depths in the lake, but the contours of this map do not correspond to the depths found by Mr. McKelvey. The line marked x,x, is the approximate boundary between the sandy sediments and gyttja. It should be noticed that it ranges in depth from less than 8 to 20 meters.

per cent organic matter. The solid materials in the gyttja consist of particles of plants, sponge spicules, diatom tests and clay- to small sand-size inorganic detrital particles. The gyttja dries to a hard and tough, black or dark gray substance which breaks and is crushed with difficulty. It absorbs water very slowly and in many cases the dried gyttja will float on

water. The sediments between the line indicated by x, x, and the shores consist dominantly of sands and larger particles although in some places there are accumulations of plant matter. There is a narrow zone of graduation from sands to gyttja.

Many fish dwell in the lake and there are some shelled invertebrates. No remains of these organisms were found in the sediments. Erosion of the shores is active in many places and the shores are the immediate places of origin of most of the clastic sediments. Some dust probably settles from the atmosphere. The organic sediments are produced in the lake or blown or drop from the surrounding vegetation.

Colors of the sands range from light gray to greenish or brownish gray. The most important mineral in the sands is quartz and it is thought that olivine may take second place although the ratio between quartz and olivine is of the order of perhaps 20 or more to 1. There is much feldspar in some samples and most samples contain particles of a dark substance which in some cases consists of greenstone or other dark rocks. Particles larger than sand-size are present in most sand samples. These consist of rocks of many kinds among which are felsite, granite, mica schist, flint, quartzite, and greenstone. Some of the large particles are also composed of transparent and milky quartz.

Roundness of the sand and larger particles varies somewhat with the samples; most contain some well rounded grains. A few samples have most of the grains well rounded, but angular and subangular particles of the same grade size are always present. Particles of the small sand and smaller sizes are always angular. Rounded particles are usually minutely pitted or frosted (mat surface). These are always associated with angular and subangular particles which exhibit no rounding or pitting, but instead have smooth shiny surfaces. It is obvious that the sandy sediments have had variable past histories. The rounded and pitted particles have had a much longer history than the angular ones. The former were released from the parent rocks a long time ago and have undergone a long transportation. It is not known where the ice acquired the sands which its melt water deposited as outwash, but the places must have been somewhere to the north. The rounded sands probably came from a sedimentary terrane and some of the transportation which they have undergone was by wind.

TABLE 9. The three quartile dimensions and coefficients of sorting and skewness of the sands from Muskellunge Lake.

Sample Number	Depth of water	Q1	M	Q2	So	Sk
6	1 meter	.156	.200	.50	1.79	1.95
14	1.5	.217	.400	.75	1.80	1.01
15	8	.175	.25	.475	1.64	1.83
17		.1875	.55	.28	1.20	1.70
18	0.15	.175	.40	2.3	3.60	2.51
19	0.5	.19	.30	.85	2.20	1.79
20	1	.14	.225	.425	1.70	1.10
21	1.5	.18	.375	1.5	2.90	1.20
34	0.9	.09	.16	.21	1.50	.73
35	2.5	.155	.218	.375	1.50	1.30
38	1	.156	.225	.475	1.70	1.40
44		.15	.20	.30	1.40	1.10
46	7	.16	.31	.45	1.70	.75
52		.19	.35	.45	1.50	.70
53	3.5	.11	.225	.244	1.50	.53
55	1	.109	.156	.206	1.40	.95
56	10	.10	.17	.19	1.40	1.04
57	10	.10	.15	.21	1.40	.93
62	20	All pebbles, no sand				
64	5	.96	.125	.325	1.80	2.17
65	1.5	.16	.21	.30	1.36	.75
68	2.5	.16	.21	.29	1.30	1.05
69	3	.07	.20	.46	2.50	.80
72	4	.19	.375	1.70	2.97	2.30
73	8	.16	.22	.39	1.50	1.30
77	2	.08	.106	.15	4.30	1.60
78	1.5	.15	.20	.26	1.30	.94
85	1	.29	.40	.50	1.40	1.07
86	1	.175	1.00	2.80	3.99	.49
90	4	.091	.125	.19	1.40	1.20
92	6	.16	.23	.49	1.75	1.50
93 Rocky	6	.187	.275	.45	1.50	1.10
101	19	.09	.187	.21	1.50	1.00
102	18	.10	.15	.212	1.40	.94
105		.25	.85	2.60	3.40	.88
106	5.5	.21	.425	1.35	2.50	1.50
108	1	.16	.19	.26	1.20	1.10
109	5	.187	.175	.225	1.30	1.00
114		.17	.25	1.60	3.10	4.35
115	19.5	.14	.18	.24	1.30	1.08
118	7	.094	.15	.206	1.50	.905
119	8	.12	.175	.225	1.40	.88
120	3	.103	.156	.212	1.40	.85
122		.088	.106	.18	1.40	1.40
123	1	.112	.175	.212	1.40	.77
124		.24	.40	1.2	2.40	1.30
125	1	.16	.237	.535	1.30	1.50
129	11	.084	.11	.225	1.60	1.56

with ice. Either of these two agencies would give a promiscuous distribution rather than a local one. This seems to be the case. It seems obvious that the distribution can not be interpreted as simple functions of depth. Neither does it seem that the distribution is one of current transportation.

However, the figures in the analyses do not reveal the complete story. This is shown by representative samples which are described below in detail. Most samples contain plant matter in all degrees of comminution. Some samples are described from the point of view of the fractions, others as the gross samples. Depths of collection are given in table. Descriptions are as follows:

Sample 6. Mixed sands compose about 90 per cent of the sample by weight. The other ten per cent by weight consists of pieces of rock with one particle having dimension of 25 by 18 by 12 mm.

Sample 7. Mixture of pieces of stems, bark, and leaves with a little finely divided vegetable matter. There is also a little sand.

Sample 14. This sample is described after it was fractioned.

over 4 mm., 2.30 per cent. Two small pebbles of granite, rest pieces of stems, bark and leaves.

2 to 4 mm., 3.00 per cent. Fifteen angular granules composed of quartz and rock, rest pieces of stems, bark, and leaves, one seed.

1-2 mm., 5.26 per cent. About one-half of the particles consists of pieces of plant matter. The other half consists of angular and subangular particles of quartz and rock.

½ to 1 mm., 21.9 per cent. About one-half of the particles are composed of plant fragments, the other half of angular and subangular particles of quartz and a few other minerals.

¼ to ½ mm., 51.8 per cent. The fraction consists mostly of angular and subangular particles of quartz and a few other minerals. Some plant fragments are present.

⅛ to ¼ mm., 10.2 per cent. One-third to one-half is composed of angular particles of quartz and a few other light colored minerals. There is a little plant matter.

1/16 to ⅛ mm., 1.3 per cent. About one-half the particles is composed of angular particles of quartz and light colored minerals. The other half of the particles consists of organic matter.

1/16 mm., 0.62 per cent. More than half is composed of organic matter, the other half of angular particles of light colored minerals.

Sample 16. The sample consists of gray sands of which some are quartz and some particles of rock. Some sands rounded, others angular. The rounded particles have pitted, or mat surface. The small particles are angular. There is no plant matter.

Sample 20. This sample contains small pebbles which are angular to subangular. Sands are quartz with both round and angular grains. The sample contains fragments of stems, bark, and leaves.

Sample 21. The sample contains one well rounded pebble. There are numerous small pebbles and granules which are angular to subangular. These are composed of rock and quartz. The large sand grains are rounded. Some of these have shiny surfaces and others are minutely pitted, or frosted (mat surface.) The small sand particles are angular.

Sample 34. The sorting of the inorganic particles is excellent and much better than is indicated by the coefficient or sorting. The value of the coefficient is modified by the presence of fragments of stems, bark, and leaves.

Sample 38. This sample contains one subangular pebble with a length of 25 mm. This was removed before analysis. The mechanical analysis is as follows.

over 4 mm., 10.94 per cent of which 1.59 per cent consists of fragments of stems and bark. The rest consists of seven pebbles of which four are angular and three subangular.

2 to 4 mm., 5.39 per cent. Contains a single fragment of a small shell. About one-half of the particles consists of fragments of stems, bark, and leaves. Other half of the particles is quartz with some feldspar and rock. The particles are little rounded.

1 to 2 mm., 6.49 per cent. About one-half of the particles consists of fragments of stems, bark, and leaves. The other half is composed of quartz with some feldspar and rock. Most particles rounded and some well rounded.

½ to 1 mm., 15.97 per cent. One-half to three-fourths is composed of angular and subangular particles of quartz; the rest is mostly pink feldspar.

¼ to ½ mm., 47.56 per cent. The fraction consists largely of rounded and subangular particles of quartz.

⅛ to ¼ mm., 12.00 per cent. The fraction is largely composed of angular particles of quartz.

1/16 to ⅛ mm., 1.04 per cent. The fraction is composed of angular particles of light colored minerals.

1/16 mm., 0.61 per cent. The fraction is composed of angular particles of light colored minerals.

Sample 44. This sample has its greatest percentage in the ⅛ to 1 mm. grades. Rounded particles are abundant in the ½ to 2 mm. grade. Quartz is the chief composing mineral. The 2 to 4 mm. grade contains thirty-seven angular to subangular particles of which one is quartz, two are feldspar and the others are pieces of rock.

Sample 53. The mechanical analysis of this sample with description of the fractions is as follows.

over 4 mm., 3.18 per cent. Consists of two pebbles, both subangular. The larger consists of granite, the smaller of quartz.

2 to 4 mm., 5.63 per cent. Composed of angular particles of quartz, feldspar and rocks. There are two fragments of stems.

1 to 2 mm., 6.35 per cent. About half consists of angular and subangular particles of quartz, the other half of angular pieces of rock. There are some fragments of stems.

½ to 1 mm., 8.43 per cent. Consists mostly of angular particles of quartz. There are some angular particles of feldspar and rock. Fragments of plants are also present.

¼ to ½ mm., 45.49 per cent. Consists mostly of angular particles of quartz.

⅛ to ¼ mm., 28.16 per cent. Consists mostly of angular particles of quartz.

1/16 to ⅛ mm., 2.78 per cent. Composed of angular particles of light colored minerals.

Sample 52. This sample from the depth of 20 meters consists of thirteen pebbles, two granules, and some fine sand. The largest pebble is 25 mm. long and 13 mm. wide and thick.

Sample 65. The mechanical analysis of this sample is as follows.

over 4 mm., 6.26 per cent. Consists of four fragments of stems, two pebbles of quartz, one of red feldspar, and eight of rock. All are poorly rounded.

2 to 4 mm., 1.61 per cent. Consists of a few fragments

of stems and twenty-six granules of which two are quartz, one feldspar, and twenty-three rock. All are subangular.

1 to 2 mm., 2.42 per cent. Composed mostly of angular particles of rock, and about one-fifth particles of quartz.

½ to 1 mm., 18.61 per cent. More than two-thirds composed of angular to subangular particles of quartz. Much pink feldspar in angular particles.

¼ to ½ mm., 68.07 per cent. Mostly angular and subangular particles of quartz.

⅛ to ¼ mm., 2.82 per cent. Mostly angular particles of quartz.

1/16 to ⅛ mm., 1.82 per cent. Angular particles of light colored minerals.

Sample 103. The sample consists of ten pebbles with a little sand. One of the pebbles is rounded, the others are angular. The diameter range of the pebbles is from 12 to 22 mm. One is of mica schist, four are of quartzite, two of felsite and three are composed of granite.

Sample 124. The mechanical analysis of this sample is as follows.

over 4 mm., 17.87 per cent. The fraction consists of twenty-two pebbles of which two are composed of feldspar, seven of quartz, one of quartzite, one of granite, and eleven of green or black rock. The pebbles range from little rounded to angular. There are some stem fragments.

2 to 4 mm., 9.87 per cent. The fraction largely consists of particles of rock, and a few particles of quartz. All particles are little rounded. Some fragments of stems and other parts of plants are present.

1 to 2 mm., 6.70 per cent. Mostly angular particles of rock and quartz. Some plant fragments are present.

less than ½ to 1 mm., 39.77 per cent. Mostly composed of particles of quartz of which some are well rounded and others highly angular.

¼ to ½ mm., 10.26 per cent. Mostly composed of quartz, particles angular to subangular.

⅛ to ¼ mm., 14.03 per cent. Mostly angular particles of quartz.

1/16 to ⅛ mm., 2.21 per cent. Composed of light colored minerals.

The foregoing descriptions show the wide variations in particles in individual samples. It is obvious that more than one

method was involved in the transportation of the sediments to the places where the samples were collected. It does not seem possible to separate the contributions due to the different methods. In addition there are the fragments of plants which are present in most samples and which are represented in mechanical analyses and are also represented in the coefficients of sorting and skewness. With contributions from currents, from ice rafting, probably from wind blowing large particles on the ice and, in the case of the plants materials from sinking after floating on the surface until water-logged, one may wonder what significance from a sedimentary point of view may be given to the results of mechanical analyses of sands deposited under such conditions as exist in waters such as those of Muskellunge Lake.

ALLEQUASH LAKE AND ITS SEDIMENTS.

Allequash Lake really consists of two lakes connected by a short and narrow passage. The western of the two parts is the smaller and the lake is about three times as long as wide. Allequash Lake drains into Trout Lake, about a mile to the west, and the eastern part has a small indraining stream on the upper end. The entire lake has an area of about 400 acres of which about two-thirds is in the eastern and larger part. The shore line has an approximate length of about five miles. The lake owes its existence to two pits in glacial outwash and is entirely surrounded by forest, mostly second growth. The relations of this lake to others considered in the paper are shown in Fig. 1.

The waters of Allequash are believed to range from oligotrophic to dystrophic. They have been determined by work done under the auspices of Doctors E. A. Birge and Chancy Juday to contain 20.72 parts of bound carbon dioxide, 12.24 parts calcium, and 4 parts magnesium per million.

Sampling of the sediments covering the bottom of Allequash Lake was done by Mr. V. E. McKelvey during the summer of 1940 and by Mr. Henry Nelson during the summer of 1941. Mr. Nelson succeeded in obtaining a core (A) with a length of 42.5 feet (a little less than 13 meters): This core is thought to have passed through the sediments which accumulated since the departure of the ice.

The sediments over considerable parts of the bottom of Alle-

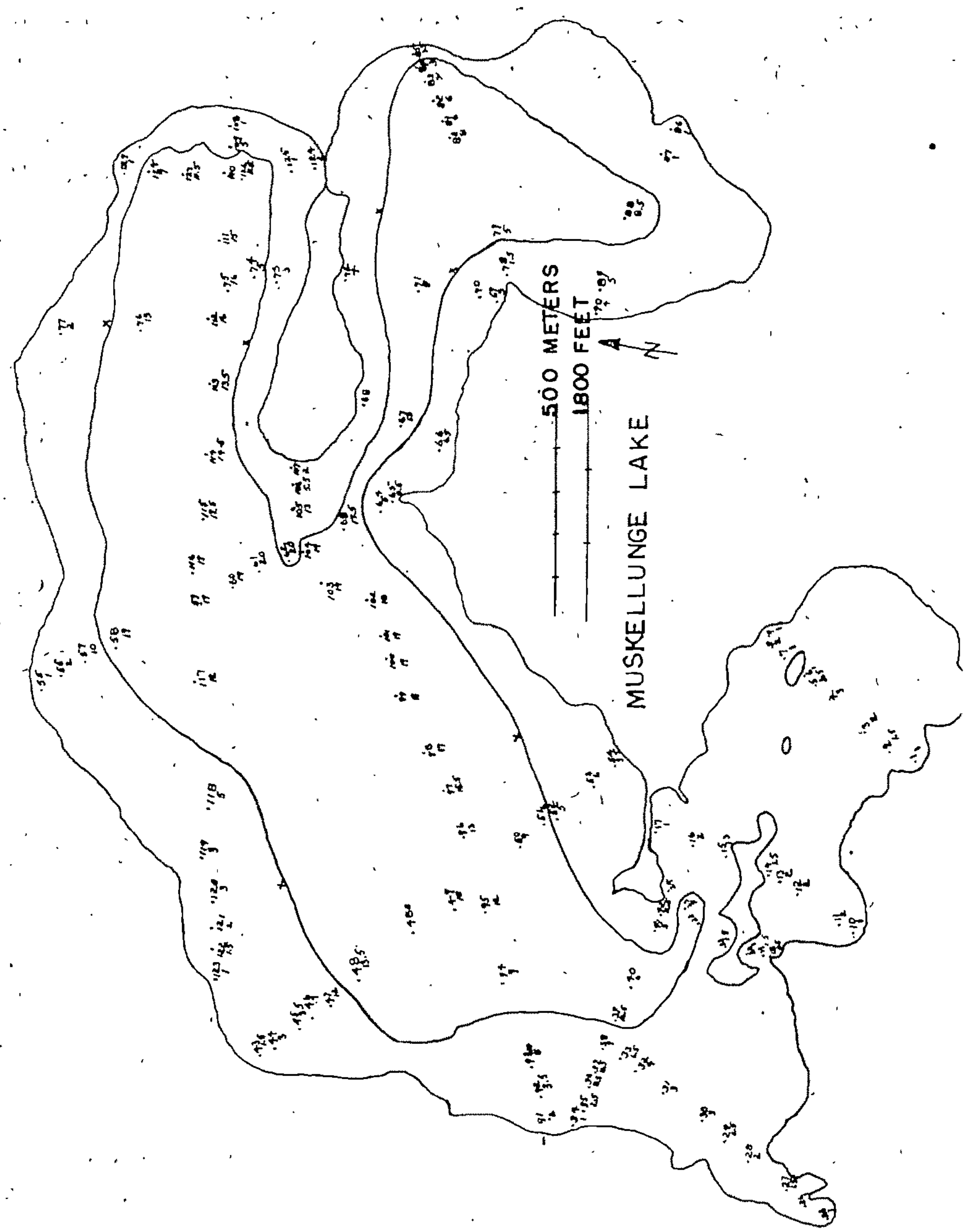

Fig. 7. Map of Allequash Lake. The upper numbers indicate the stations, the lower the depths at the stations. The shore of this lake was studied in sectors. This study established that the lake is receiving few sediments from its shores.

quash Lake contain large quantities of combustible gas during some months of the year, particularly during July and August. The gas rises in abundant bubbles as a boat is rowed over waters which are not more than two meters deep. It is a task of only a few minutes to fill a quart milk bottle with the gas.

The western and smaller of the two basins (Fig. 7) is nearly filled with organic-rich sediments and the top of the sediments is only a short distance from the surface of the water. The sediments, however, are little consolidated and an oar can readily be pushed into them with immediate large escape of gas. The eastern and larger basin is not so full of sediments and depths of water as great as eight meters (25 feet) are present.

For purpose of study of the sediments on the shore of the lake, it was divided into 20 sectors based on the character of the shore and the shore and shallow water sediments. This work was done by Mr. Nelson with the objective of determining the extent of contributions of sediments by the shores. Figure 7 shows the positions of the sectors. Their descriptions are as follows.

1. No beach, vegetation to water's edge and beyond this bottom covered with sand, pebbles, gravels, and cobbles for a short distance outward where these sediments abruptly pass into black to dark gray muddy gyttja. Much fallen timber is over the shallow bottom.

2 to 5. No beach. Boggy shore, and gyttja covers bottom.

6. Beach about one-third of a meter wide and composed of sand. Sediments consist of sand for a short distance from shore and then pass into gyttja. Vegetation extends to edge of water.

7. No beach. Pebbles, cobbles, and boulders form narrow offshore deposits and pass abruptly into gyttja.

8. Beach about one-third meter wide in some places, composed of sand. Offshore deposits of sand. Most parts of shore boggy and the shallow bottom supports a plant growth based on gyttja.

9. No beach. Steep bank, water deepens quickly. Offshore sediments sands which pass outward into coarser sediments. The shallow water sediments about the point on the north end consist of large boulders with diameters to a half meter or more. Just north of the point is a small bay of which the

shallow bottom is covered with sand. Considerable parts of the shore are being rapidly eroded.

10. No real shore, shallow bottom covered with gyttja supporting plants and gradually passing into bog.

11. No real shore, shallow bottom covered with gyttja passing into bog.

12. No beach. Sands, pebbles, cobbles form offshore deposits. No active erosion.

13. No beach. Shallow bottom covered with gyttja passing into bog.

14. No beach. Shore covered with vegetation in the form of bog which passes into gyttja on the lake bottom.

15. No beach. Sands, pebbles, and cobbles form offshore deposits, water deepens slowly. Gyttja forms deposits in small bays. Shore covered with vegetation which is bog over the southern half.

16. No beach. Shore a bog passing into gyttja.

17. No beach. Offshore deposits of sand, shore a bog.

18. No beach. Offshore deposits of gyttja, shore a bog.

19. No beach. Sand and small pebbles form offshore deposits. Shore a bog.

20. No beach. Offshore deposits of gyttja, shore a bog.

The analysis of the shores shows that only along sectors six and eight is there a beach and this is very narrow. Only along the shores of sectors seven and nine is there any erosion. It is thus obvious that the shores of Allequash Lake are now contributing very little in the form of inorganic sediments. This evidently accounts for the occurrence of gyttja in very shallow water and its nearness to the shores at most places, and the fact that gyttja covers the bottoms to the shores of sectors 2 to 5, 10, 12, 14, 16, 18, and 20. The other shallow bottoms for short distances from shore are covered with clastics in the range from sands to boulders.

Foregoing paragraphs show that Allequash Lake is now acquiring few inorganic sediments from its shores. This is evidently due to the dimensions of the lake and probably also to the shape, particularly to the shape of the western basin. It probably is also due to the protection afforded by the forest over the surrounding surface. Some inorganic sediments are dropped from the atmosphere, but these can hardly be great. The small inlet on the eastern end of the lake may also contribute a small volume of inorganic sediments. The result is

that the sediments are high in organic matter. This has been derived from plants and animals dwelling in the lake and also from the surrounding vegetation. The relative quantities from the two sources do not seem possible of determination.

DESCRIPTION OF THE SEDIMENTS.

Twenty-seven samples were taken with the Ekman dredge at stations indicated on the map of figure 6 by the numbers 1 to 27. Every sample contained abundant organic matter. Narrow bands of sands and silts with occasional boulders exist along some parts of the shore as indicated in the descriptions of the shore. These sediments were not sampled. Three core samples were taken with the Jenkin and Mortimer core sampler in places indicated by letters B to D, and one core was taken with the Wilson core sampler at the place indicated by the letter A. Results of the sampling with the Ekman dredge are given in table 11.

TABLE 11. (Table giving depth of water, character of sediments, moisture content, per cent of organic matter based on loss on ignition, and per cent of lignin in the organic matter.

Sample Number	Depth of Water	Character of Sediments	Moisture Content	Per Cent of Organic Matter Based on Loss on Ignition	Percentage of Lignin in Organic Matter
	Meters	Western Basin			
1	0.75	Sandy black gyttja	90.7%	20%	23%
2	1.00	Sandy black gyttja		37	45
3	1.50	Slightly brown gyttja		47	28
4	2.00	Brown gyttja	96.0	69	41
5	2.50	Greenish brown gyttja		80	20
6	2.00	Greenish brown gyttja		47	21
7	2.00	Greenish brown gyttja	97.2	71	30
8	3.00	Greenish brown gyttja		80	21
9	2.50	Greenish brown gyttja		75	32
10	2.50	Sandy black gyttja	94.5	44	18
11	1.50	Black gyttja		79	26
12	1.50	Black gyttja		79	40

Sample Number	Depth of Water	Character of Sediments	Moisture Content	Per Cent of Organic Matter Based on Loss on Ignition	Percentage of Lignin in Organic Matter
	Meters	Eastern Basin			
13	1.00	Greenish brown gyttja	95.3%	56%	34%
14	2.00	Greenish brown gyttja		31	38
15	5.50	Greenish brown gyttja		54	23
16	6.00	Greenish brown gyttja	95.4	60	44
17	6.50	Greenish brown gyttja		55	43
18	3.50	Greenish brown gyttja		54	37
19	3.00	Greenish brown gyttja		34	39
20	7.00	Black gyttja	95.2	60	39
21	8.00	Black gyttja		41	35
22	7.50	Black gyttja		55	40
23	2.50	Sandy dark gray gyttja		42	40
24	6.50	Black gyttja	94.5	44	57
25	7.50	Black gyttja		52	26
26	2.50	Greenish gyttja	93.8	50	30
27	1.00	Greenish gyttja		78	55

The average water content of the surface samples of the sediments of the eastern basin is 94.8 per cent and of the western or smaller basin 94.6 per cent. These figures are essentially the same and thus show an essential constancy in kinds of sediments deposited.

Nearly every sample is typical gyttja which has a nearly black color in gross appearance, but in thin layers under a microscope is a pale greenish-yellow gel in which are enmeshed diatom tests, sponge spicules, fragments of plant matter, pollen grains, and inorganic particles. Fish and tadpoles dwell in the lake, but no remains of these animals, or any shells were found in the sediments.

The per cent of organic matter in the sediments is shown in the fifth column of the table. This exceeds 50 per cent in 16 samples and in an additional case it is just 50 per cent. Only in ten samples is it less than 50 per cent, and in six of these it exceeds 40 per cent and in only four samples is it less than 40 per cent. The map shows the close correlation between the character of the shore and the percentage of organic matter. Samples 1, 2, 14, and 19 contain less than 40 per cent organic matter. Samples 1 and 2 were obtained in the channel between the two basins with the shore close by in each case and an occasional current from the upper to the lower basin to carry

away organic matter. Sample 14 was obtained north of the point of sector 9 where the shore is being eroded and the station of sample 19 is close to a sandy beach. Samples 3, 6, 10, 21, 23, and 24 have less than 50 per cent organic matter and each, with the exception of sample 21, is from a station where it may be expected the shore supplied inorganic sediments. The map shows that, in general, the samples from the larger of the two basins contain less organic matter than those from the western and smaller basin. This is because the shores of the latter basin can contribute very little sediment which is not the case in the larger basin. The average for the larger basin is 51 per cent; for the smaller basin it is 66 per cent. There seems to be little consistency in the percentage of lignin in the organic sediments with the percentage ranging from as little as 18 to as high as 55. The results, however, are only approximate.

Core B is from a station in the western basin, core C and D are from the eastern basin. Core A is from the western part of the lower or western basin. A sample was taken with the Ekman dredge at each station.

Core A shows a thickness of a little more than 13 meters (42.5 feet) of organic rich sediments and encountered gray sand at that depth. The sediments consisted of brown to brownish-black gyttja to the depth of two meters (about six feet). These sediments showed little coherence. Below two meters the color changed with depth through loss of brown. At seven feet the gyttja became fairly coherent and acquired a greenish shade to its blackness. This increased in intensity to the bottom. The organic content was fairly consistent to the bottom of the gyttja and in the range from 70 to 80 per cent. As noted above, sand was encountered at 42.5 feet (about 13 meters). This sand is thought to mark the time of the disappearance of the glacier.

Core B extended to a depth of six meters (20 feet) and consisted of brownish-black gyttja to about five meters (16 feet) and then greenish-black gyttja to about six meters (19 feet.) There was then eight inches of gray sand and silt with organic matter and then gray sand and silt for four inches. Core C was carried to the depth of 5.91 meters (19.5 feet) and consisted of greenish-black gyttja. The bottom of the gyttja was not found. Core D was carried to the depth of about five meters (16 feet.) The sampler penetrated an additional foot but no sample was obtained.

The water content of the samples from the cores was found as follows.

TABLE 12. Water contents of the sediments from cores in Allequash Lake.

Position of Sample in Core	Content of Water
Core A	
Ekman	97.5%
5 feet	96.0
15	89.6
20	94.8
23	95.0
27	95.0
32	94.0
36	93.2
39	90.5
Average including Ekman sample	94.8
Core B	
3–4 feet	95.0%
11–12	92.8
15–16	94.7
19–20	56.5
Core C	
Ekman	94.4%
5–6 feet	93.6
9–10	93.1
13–14	91.8
15–16	90.0
17	89.7
Core D	
Ekman	94.3%
5–6 feet	92.6
9–10	92.0
13–14	91.0
17–18	90.8
18–19.5	90.2

The samples show a very small decrease in water with depth and it seems obvious that organic rich sediments such as these yield water very slowly and that there has been very little expulsion of water from the bottom sediments since they were deposited following retreat of the ice some 25,000 to 50,000 years ago. The possible loss of water is of the order of one to two per cent. There also seems to be a small decrease in content of organic matter with depth which renders it obvious that elimination of organic matter by bacteria and other organisms is very small once the sediments are covered by other sediments. Lithification of these sediments would produce a carbonaceous

or bituminous shale, presumably the latter. If all the water was expelled the maximum thickness of about 13 meters (42.5 feet) would be reduced to less than one meter or three feet, thus giving a rate of deposition of about one meter in 25,000 to 50,000 years.

No stratification planes of any kind were found in the sediments of any of the cores taken from Allequash Lake. This is ascribed to the similarity of the sediments from year to year and to reworking of the sediments by organisms dwelling in the sediments although it must be admitted that these do not seem to be either numerous or varied. It is known that numerous larvae dwell in the sediments at times and that the top sediments contain considerable, but not large numbers of bacteria. The number is by no means as large as was expected when the studies of the northern soft water lakes was undertaken.

The maximum thickness of sediments deposited since the departure of the glacier was found in the western basin at the position of core A where about 13 meters (42.5 feet) was found. This was reduced to nearly six meters (19 feet) at the position of core B. The sediments deposited in the eastern basin since the departure of the ice are known to have a minimum thickness of about six meters (19.5 feet) at the position of core C without the entire thickness having been penetrated. The bottom of the gyttja is thought to have been reached at about 4.8 meters (16 feet) at the position of core D.

GENERAL CONCLUSIONS.

1. The dominant and most abundant form of organic sediment in lakes of the character described in this paper is a pale greenish-yellow gel which is in the form of small globules. This is thought to have been precipitated from suspension through flocculation.

2. Recognizable organic animal remains consist of sponge spicules and a very rare occasional shell. Recognizable plant remains consist of fragments of stems, bark and leaves and tests of diatoms.

3. The organic-rich sediments of all depths penetrated contain water generally to more than 90 per cent.

4. Approximately 50 or more per cent of the dried organic-rich sediments collected below a depth of three meters are composed of organic matter.

5. Rates of deposition of the organic-rich sediments are very slow and are in the range of one meter of solid sediments in 25,000 to 100,000 years.

6. The maximum thickness of wet organic-rich sediments was found in Allequash Lake with about 13 meters (42.5 feet).

7. No stratification of any kind was found in any of the organic-rich sediments.

8. Several methods of transportation were concerned in the deposition of the sands about the shores. Most sands contain organic matter.

9. Because of the several methods of transportation and the inclusion of organic matter, mechanical analyses of the clastic sediments have little sedimentational significance.

10. Mechanical analyses of the organic-rich sediments are considered to have no sedimentational significance so far as transportational agencies are concerned. Several agencies were involved in their transportation; most were probably in a flocculated condition when deposited and there is no assurance that existing dimensions are those present when deposition took place.

11. The organic-rich sediments seem to have undergone few changes following deposition. Colors are almost the same and the content of organic matter and water content are very much the same at the bottom and the top of every core obtained.

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UNIVERSITY OF WISCONSIN,
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OBITUARY.

GUY E. PILGRIM, 1875-1943.

Henry Guy Ellcock Pilgrim, Fellow of the Royal Society and sometime Superintendent of the Geological Survey of India, died at Upton near Didcot, in the English County of Berkshire, on September 15, 1943.

He was born into an old colonial family at Stepney, Barbados, on December 24, 1875, the son of Henry Ellcock Pilgrim and Beatrice Lucy Wrenford. He matriculated at Harrison College on the same island and his education was continued at University College, London, where he received the degree of Bachelor of Science in 1901, and that of Doctor of Science in 1908.

Meanwhile, the field of his all-important contributions to geological science was foreshadowed by his appointment to the Geological Survey of India in 1902. He was promoted to Superintendent in 1920, and continued in that office until his retirement in 1930. Thereafter, he made his home at Upton, but spent much of his time in active work as a member of the supernumerary staff of the Department of Geology, British Museum (Natural History).

His early geological explorations in the Persian Gulf region of Arabia and Persia were described in two Memoirs of the Geological Survey of India (XXXIV, 4, 1908 and XLVIII, 2, 1924). He was the first European to visit parts of Trucial Oman, and the first geologist to explore Bahrein Island, where he discovered the dome structure, a knowledge of which resulted in the present extensive oil exploitation there.

However, his greatest contributions to Geology have been in the fields of the Cenozoic continental stratigraphy and vertebrate paleontology of the sedimentary formations of India and adjacent countries, beginning with the description of fossil Proboscidea from the alluvium of the Godavari River, in 1905. Following in the footsteps of Falconer, Cautley, and Lydekker, he ably devoted rare energy and zeal to the manifold problems of Siwalik stratigraphy and paleontology. As noted by the late W. D. Matthew, "The admirable later work of . . . Pilgrim was the first to make clear distinctions between the successive faunas, and added very largely to the faunas. . ." E. H. Colbert has pointed out the fact that "Dr. Pilgrim virtually opened the field in the discovery and study of Lower Siwalik vertebrates" and stratigraphy. His "Preliminary Note on a Revised Classification of the Freshwater Tertiary Deposits of India" (Rec. Geol. Surv. India, LX, 3, 1910) gave the

world the first accurate and modern understanding of this great problem, and fifty of the two hundred species dealt with were discovered by him. Early in his career, he found and studied the first of numerous specimens of fossil great apes. His many finds and extensive research bearing on these fossils of paramount human interest, apart from all his other contributions to science, would have insured his reputation as one of the most distinguished vertebrate paleontologists of this century.

Subsequent years brought many new fossil discoveries and a great number of additional studies in the same field, as a result of his vigorous collecting, observation, and productive research. In addition to numerous shorter publications, principally appearing in the Records of the Geological Survey of India, he was the author of an important series of Memoirs in the Palaeontologica Indica. These included "The Fossil Giraffidae of India," "The Vertebrate Fauna of the Gaj Series," "The Perissodactyla of the Eocene of Burma," 'The Fossil Suidae of India," "A *Sivapithecus* Palate and Other Primate Fossils from India," "The Fossil Carnivora of India," and "The Fossil Bovidae of India." The "Catalogue of the Pontian Carnivora of Europe" (Cat. Brit. Mus., 1931), and "Siwalik Antelopes and Oxen in the American Museum of Natural History" (Bull. A. M. N. H., LXXII, 7, 1937) should be mentioned also. This latter work was the fruit of his visit to the United States in 1932, where his admirable personal and scientific character won him many fast friendships among those in this country who had not had the privilege of knowing him previously. The "Catalogue of the Pontian Bovidae of Europe" (Cat. Brit. Mus., 1928) was written in collaboration with A. T. Hopwood.

He was President of the Geological Section of the Indian Science Congress in 1925, a Fellow of the Geological Society, a Corresponding Member of the Paleontological Society of America, a Fellow of the Asiatic Society of Bengal, and on March 18, 1948, was elected Fellow of the Royal Society. The news of this last honor was most gratifying to his friends.

No tribute in memory of him would be complete without mention of one of his most important services to science: the encouragement of others in studies in his chosen field. Many younger men were privileged to receive his generous friendship, disinterested advice, and inspiring help, to their own great benefit. With his death, paleontology and stratigraphy have lost a distinguished leader.

GEORGE EDWARD LEWIS.

SCIENTIFIC INTELLIGENCE

PHYSICS AND CHEMISTRY.

Electrical Counting; by W. B. LEWIS. Pp. vii, 144. Cambridge University Press, 1942 ($2.50).—The Cavendish Laboratory has been an active center of nuclear research, and many methods of counting electrically charged particles have been developed there. Publication of a systematic summary of these methods, together with a survey of the entire field, such as is set forth in the present book, will be welcomed by all workers who have occasion to use counting devices. H. MARGENAU.

Man and His Physical Universe; by F. C. JEAN, E. C. HARRAH, F. L. HERMAN, and S. R. POWERS. Pp. viii, 608. New York, 1943 (Ginn and Company, $3.25).—The book is a revision of the authors' "Man and the Nature of His Physical Universe" which was published in 1934. It represents a text for a science-survey course on the College-Freshman level and includes astronomy, physics, chemistry, geology, and a good deal of engineering. Written with much pedagogical skill. H. MARGENAU.

The Chemical Background for Engine Research. Frontiers in Chemistry, Vol. II; edited by R. E. BURK and OLIVER GRUMMITT. Pp. 297; many figs. and tables. New York, 1943 (Interscience Publishers, Inc., $3.50).—This is a reprint of a series of lectures delivered at Western Reserve University. The subjects and the lecturers were: A survey of combustion research, E. F. Fiock; Chemical thermodynamics of hydrocarbons, F. D. Rossini; Synthetic methods for hydrocarbons, F. C. Whitmore; Kinetics of flame and combustion, G. von Elbe; The experimental side of combustion research in engines, Bernard Lewis; Some physiochemical aspects of lubrication, Otto Beeck. GEORGE M. MURPHY.

Physical Biochemistry; by HENRY B. BULL. Pp. iv, 347; 94 figs. New York, N. Y., 1943 (John Wiley and Sons, Inc., $3.75).—"This volume is an outgrowth of a series of about thirty-six lectures which" have been given "to graduate students in biochemistry, physiology, bacteriology, and neurology" and which were attended by medical students. Many of the aspects of physical chemistry which enter in biological phenomena are discussed in direct application to biochemistry. An experimental viewpoint is maintained throughout the book with many references to the literature. Some use is made of thermodynamics. The book, both in subject matter and format, is quite modern. SCOTT E. WOOD.

GEOLOGY.

The Control of Reservoir Silting; by CARL B. BROWN. Pp. ii, 166; 58 figs. U. S. Dept. of Agriculture, Miscellaneous Publication No. 521, 1943 (Government Printing Office, Washington, 25 cents).—Here is an exceptionally interesting and informative treatise on a subject that looms large in the national economy. The author, head of the sedimentation section, Office of Research, U. S. Soil Conservation Service, has responded to widespread requests for information on methods of controlling or reducing the accumulation of silt in impounding reservoirs used for water supply, irrigation, and power production. Since 1900 there has been a phenomenal increase in the number and the scale of such reservoirs in this country, with an acceleration in construction that was halted abruptly by the war. In 1941 there were on record about 8,900 dams and reservoirs, representing an investment of nearly four and a half billions of dollars. Many of these expensive works were constructed with little or no consideration of the silting problem, and there has been enormous loss of value as a consequence. In the words of the author, "As a nation, we have used our reservoir sites with abandon, much as we have used our soil, turning from depleted or exhausted areas to fresh fields, with little view to the ultimate limits of the resources." The losses already sustained are truly staggering. Nearly two thousand smaller reservoirs have been completely filled with debris; and it is estimated that the annual cost of silting—measured by the steady loss in capacity of our numerous expensive reservoirs—is more than 50 million dollars. Fortunately there is a growing consciousness of the need for sounder engineering practice in designing and maintaining reservoirs. The need to conserve this resource is especially urgent during the war, since we do not have materials and labor for constructing new dams, and yet the demands on existing reservoirs are greater than ever before.

The large number of effective steps in a comprehensive program to control silting may astonish the uninitiated. Ideally the planning should begin with selection of the reservoir site. It is important that a suitable minimum ratio of reservoir capacity to watershed area be provided. This minimum ratio varies from 75 acre-feet per square mile in the Southern States to 250 acre-feet per square mile in the Texas-Oklahoma region; it depends on the rate of erosion, which is determined in part by vegetal cover on the watershed. An example of improper judgment in this matter is furnished by a water-supply reservoir built in Kansas a few years ago at a cost of $150,000. Although the capacity was ample for the community to be served, the drainage area above the dam was so large that the storage capacity was only 0.14 acre-foot per square mile. The reservoir was entirely filled with sediment within a year of its completion.

All dams should be designed with gates or with outlet works adequate to care for silting problems that may arise. Some of our most important dams have not been thus equipped, and it is not feasible to install such works after the dam is built. However, complete study of the reservoir problem may reveal the inadvisability of by-passing silt, in which case ample provision should be made in the size of the reservoir to care for a large volume of sediments. Thus in the planning of Boulder Dam nearly one-fourth of the resulting reservoir capacity was allotted for sedimentary deposits.

Much can be done to prevent sediment from entering a reservoir. One standard practice, which dates back to the days of Rome under the Caesars, is the construction of settling basins upstream from the head of the reservoir. An excellent example in this country is the basin formed by the Mono debris dam above the Gibraltar reservoir, near Santa Barbara, California. The occasion for this project was an emergency created by forest fires which set the stage for catastrophic erosion in part of the watershed, with the consequent threat that the reservoir would be speedily filled with sediment. The large Mono settling basin, formed by a substantial concrete dam, was entirely filled with debris in two seasons. Another device to cause effective settling of silt above reservoirs is the planting of shrubs or trees along the stream courses: the tamarisk is proving to be especially valuable for this purpose in some of the Southwestern States. Other methods of keeping silt out of a reservoir include the building of the reservoir off-channel, with provision for admitting water only after the content of sediment has been greatly reduced. A variant of this practice is the construction of desilting works such as those at the head of the All-American Canal, in California, which consist of large concrete settling basins arranged in pairs. Still another method is the construction of by-pass canals and conduits through which sediment-laden flood waters are shunted for protection of the reservoir.

In regions characterized by heavy seasonal rainfall it is good practice to release a large share of the runoff, through low-level sluice gates in the dam, and to hold back only the comparatively clear water during the late stages of the rainy season. The Bhatgarh reservoir in India and the great Aswan reservoir in Egypt have been kept nearly free from sediment by this practice. Another method of controlling the deposition of sediment, which however is still largely in the experimental stage, consists in the venting of silt-laden density currents which are known to flow through to the dam in several large reservoirs, notably in Lake Mead and in the Elephant Butte reservoir.

Many reservoirs can be saved from complete destruction only by removal of sediments. Actual excavation and dredging are prac-

ticed, though ordinarily the expense is high. In some situations the commercial value of sand and gravel makes excavation profitable. More common practices are periodic draining and flushing, and flood sluicing; such methods are possible only if the dam is equipped with suitable gates. Much has been learned about the most effective techniques of flood sluicing, which is one of the oldest methods of reservoir silting control.

In the long view, one of the most essential steps in solving the large problem of reservoir silting is effective control of erosion in the watershed. A large part of the sediment that destroys the reservoirs consists of soil and subsoil washed from farmlands improperly tilled, from overgrazed range, and from steep slopes once protected by forest cover but recently denuded either by ax or by fire. Soil erosion is a mighty scourge from which this country has suffered much and which will continue to bring afflictions directly and indirectly. In most parts of the nation the problem of reservoir silting, which now looms large, would be reduced to reasonable proportions if the greater problem of unnecessary soil wastage could be brought under control. CHESTER R. LONGWELL.

PUBLICATIONS RECENTLY RECEIVED.

Chicago Areal Geologic Maps: Surficial geology of quadrangles of the Chicago area; by J. Harlen Bretz. Topographic base surveyed in cooperation with the U. S. Geological Survey in 1925; geologically surveyed in 1930-32. Scale 1/24000. Illinois State Dept. of Registration & Education. Maps Nos. 1-15, 17-19, 21.

Illinois Geological Survey. Report of investigations as follows: No. 47. Wildcat drilling in Illinois since 1936 with discussion of Prospects for Further Discoveries and Table of Wildcat Wells completed in 1942; by C. W. Carter. No. 88. Chemical Characteristics of Illinois Crude Oils with a discussion of their Geologic Occurrence; by O. W. Rees, P. W. Henline, and A. H. Bell. Urbana, 1943.

Province of Alberta. Report No. 34. Geology. Part I. General Geology of Alberta, Part II. Rock Salt Deposit at Waterways, Part III. Geology of Alberta Soils, Part IV. Relief Model of Alberta and its Geological Application, Part V. Coal Areas of Alberta; by J. A. Allan. Edmonton, 1943. Price, $1.50.

Air Navigation Work Book. A Course in Graphic Mathematics; by A. D. Bradley and C. B. Upton. New York City, 1943 (American Book Company, $.88).

Galaxies; by H. Shapley. Philadelphia, 1943 (The Blakiston Co., $7.50).

Vegetable Fats and Oils; by G. S. Jamieson. Second edition. New York, 1943 (Reinhold Publishing Corp., $6.75).

The Cretaceous Rocks of South India; by L. Rama Rao. Lucknow, India, 1942.

Smithsonian Institution War Background Studies. No. 16. Island Peoples of the Western Pacific Micronesia and Melanesia; by H. W. Krieger. No. 17. Burma—Gateway to China; by H. G. Deignan. Washington, 1943.

U. S. Geological Survey. Bulletins as follows: 928-C. Adsorbent Clays. Their Distribution, Properties Production and Uses; by P. G. Nutting. Price, $.20; 928-D. Manganiferous and Ferruginous Chart in Perry and Lewis Counties, Tennessee; by E. F. Burchard. Price, $.25; 931. Strategic Minerals Investigations, 1941. Pt. 1, A-J; by E. Callaghan, et al.; 939-D. Geophysical Abstracts III October-December, 1942; compiled by W. Ayvazoglou. Price, $.10; 940-B. Manganese Deposits of the Elkton Area, Virginia; by P. B. King. Price, $.75; 940-C. Geophysical Surveys in the Ochoco Quicksilver District, Oregon; by E. L. Stephenson. Price, $.50; Professional Papers as follows: 196. Geology and Biology of North Atlantic Deep-Sea Cores between Newfoundland and Ireland; by W. H. Bradley and others. Price, $.10; 205-A. Relative Abundance of Nickel in the Earth's Crust; by R. C. Wells. Price, $.10.

Mississippi Geological Survey. Bulletin 53. Clay County, Geology; by H. R. Berquist. Tests; by T. D. McCutcheon. Fossils; by V. H. Kline. University, 1943.

Illinois Geological Survey. Report of Investigations No. 99. High-Purity Dolomite in Illinois; by W. H. Willman. Urbana, 1943.

SPECIAL NOTICE.

The following Japanese journals and publications have not been received by the principal libraries of this country, but it is possible that separates of some of the articles contained therein may have been sent to individual American geologists and paleontologists.

1. Contributions from the Institute of Geology and Paleontology, Tohoku Imperial University, Sendai, Japan. Nos. 1-32, 1921-39, inclusive. (In Japanese language—not to be confused with Science Reports of this same university.)
2. Bulletin of the Tropical Industrial Institute, Palau. Vol. 1, 1938 to date.
3. Jubilee publication in commemoration of Prof. H. Yabe—60th Birthday, Vol. 2, 1940.

Some of the above material is urgently needed at the present time. If any of these publications are available for loan or for photographing, please notify promptly the Chairman, Division of Geology and Geography, National Research Council, 2101 Constitution Ave., Washington, D. C.

American Journal of Science

MARCH 1944

GENERATION OF MAGMA BY FRICTIONAL HEAT.

J. S. DeLURY

ABSTRACT. Indications that the crust of the earth is strong and thick into depths of 700 kilometers or more, together with evidence that abundant igneous rocks correspond in composition to shallow earth layers, require an appeal to magma sources other than the subcrustal weak shell of isostasy which is commonly accepted as an inherited and potential source. A hypothesis is offered to explain the origin of magmas within the crust by appealing to mechanical sources of heat. The failure of a thick crust, brought about by thermal contraction of the earth, is considered to be effected by a piecemeal operation involving different parts separately during a long period of time, rather than by a brief and final collapse embracing the entire structure. Elastic downwarping of the crust to form geosynclinal depressions is followed by a long process of failure of the lower and major part along one or several underthrust fault planes. This failure provides a plausible explanation of plutonic earthquakes. The outer shell of the crust is the last part to fail. Owing to its greater compressibility it is not compelled to yield until after deeper layers have been relieved of the horizontal compressive stress. This manner of failure prescribes the slipping of large areas of thick crustal shells over and under each other with a development of enormous quantities of frictional heat. Magmas are accordingly created in more or less continuous sheets along nearly horizontal fault planes beneath wide regions. Thermal expansion leads to elevation of these regions, so that, when the outer crustal layer fails, a "head" exists above the sheet of magma derived in the failure. Regional subsidence drives the magma forcefully into regions of lower "head" and in this process additional mechanical heat for magma generation is supplied by friction in the highly viscous magma. Applications of the hypothesis to explain major deformations near the surface are indicated.

INTRODUCTION.

THE uncertainty that surrounds the fundamental problems of the earth's crust is apparent in discussions of the relations between intrusion and deformation, of the causes of diversity of igneous rocks, and of the sources of magma. These igneous problems are related and a solution of one would likely clear up the others. Local structures sometimes suggest that intrusion causes deformation. Elsewhere relations indicate that deformation accommodated a passive entry for magma. Neither interpretation is significant because in both instances

effects are too remote from ultimate causes to decide them. Similar difficulties confront attempts to account for the compositional diversity of igneous rocks. Notwithstanding plenty of local though trivial signs of both differentiation and assimilation, these signs are so remote from ultimate sources that the variety and nature of parental magmas are highly conjectural. Plainly the third problem, that of the sources of magma, is the most fundamental and its solution might throw light on the others. Here the wide range of views emphasizes the incompatibility of assumptions used by different authorities.

A body of magma is either inherited or is created locally. A persistent view that a relatively thin crust overlies a layer of potential magma has lent support to the concept of inheritance. The assumed weak shell of isostatic theory has been accepted in many quarters as more or less definite proof of this view and as an indication that all magmas come from subcrustal regions. The same concept, coupled with the evidence for compositional zoning in the earth, suggested further that parental magmas, coming as they do from the one subcrustal layer, are all of one or closely similar composition. Hence arose the compelling need of magmatic differentiation in explanation of rock diversification, a process which implies that there is no primary granitic magma but that the prevailing masses of continental rock are wholesale differentiates of basic magmas supplied by the subcrustal weak shell. The difficulties surrounding this explanation of the origin of granite batholiths are enough in themselves to warrant a thorough search of the possibilities for securing a source of granite magma within the crust.

That inherited reservoirs of magma exist in the crust seems incredible, and especially in those shallow layers where granitic compositions are supposed to prevail. Accordingly, all possible means for local liquefaction in the crust should be examined. For example, the view is recurrent in geological literature that the granitic cores of mountains may have resulted from magmas generated by the mechanical heat of crushing and friction. The chief objection to this view comes from the evidence that these magmas are not products of fusion in place but have migrated into the folded region. The quantity of available mechanical heat seems to be adequate and an attempt will be made in the following pages to overcome objections.

Other suggestions have been made to account for a local

generation of magma, notably radioactive heat and heat from chemical reaction. The former has not been substantiated. Moreover, radioactivity would tend to eliminate itself as an active breeder of magma during the long igneous history of the earth. Regarding thermal effects from chemical reaction, it is difficult to imagine important chemical activities within the strong and relatively cool rocks of the crust.

A serious dilemma is faced in the search for magma sources. On the one hand the view that there is an inherited zone of magma or near-magma beneath the crust is precarious in the light of the evidences that the crust is strong as a whole into depths of several hundred kilometers. On the other, while compositional evidence points to a relatively shallow source for most magmas, no plausible means for generating magma in the outer and cooler parts of a thick and strong crust have been substantiated. It is the purpose of the present paper to suggest such means, but conflicting assumptions must be examined first with a view to obtaining a decisive picture of controlling conditions in the earth.

CRUCIAL EVIDENCES BEARING ON THE SOURCE AND ORIGIN OF MAGMA.

The most abundant igneous rocks of both ancient and modern formation are granites and allied types of continental masses, and members of the basalt-gabbro clan which seem to dominate in oceanic regions. Broad geologic evidences and more precise geophysical data indicate that these most abundant rocks correspond in composition to the outermost shells of the earth comprising a thickness variously estimated at a few tens of kilometers. More basic intrusives, typified by peridotite and presumably from deeper regions, are relatively minor constituents of the visible parts of the crust. Compositional evidence accordingly suggests a correspondingly shallow source of most parental magma. Hence, to conclude that magmas come from inherited sources, it is necessary to assume either an unbelievably thin crust or a derivation of granitic rocks by differentiation from more basic magmas originating in deeper levels. Geophysical evidence, however, seems to decree that there is no weak shell or zone of potential magma to supply material for the abundant intrusives of the outer lithosphere, and accordingly that search must be made for means of creating magma in the shallow regions of the granitic and basaltic layers.

In view of the known effect of volume compression on the strength of rocks, thermal evidence seems to be definitely opposed to the isostatic assumption of a weak shell supporting a relatively thin crust, but suggests rather that strength persists into depths of hundreds of kilometers. Jeffreys' estimate[1] of the distribution of temperatures in depth leads to the conclusion that in general rocks are well below their fusion points into depths of 400 and perhaps 500 kilometers. After a later examination of additional data the same writer drew the following conclusions concerning the possibilities of inherited magma existing in a thick crust:

"Nothing in the new results encourages the hope that fusion temperatures are a normal feature at any depth within the crust. The approximate reproduction of the ultimate steady temperature given in 'The Earth' shows that the vertical distribution of temperatures shown on p. 154 needs little change as far as the present data are concerned. This is really not a defect. For though volcanoes exist, a generally fused layer would lead to absence of ocean tides and to a perfection of isostasy that certainly contradicts the facts. It still appears that volcanoes are a special phenomenon and their explanation cannot be found in the average temperature distribution with depth."[2]

These conclusions, derived from the thermal history and thermal state of the earth, are confirmed by deductions from low thermal gradients measured in several mines. The lowest gradient is the logical one to project for indications of temperatures at greater depths, and it seems to defy being reconciled to the existence of a continuous shell hot enough to be weak at depths less than several hundred kilometers.[3]

Seismological data confirm the thermal evidence that the crust is thick and strong. Deep-focus earthquakes give the most definite affirmation. These are recorded in all levels down to 700 kilometers or more. Seismologists[4] now generally agree

[1] Jeffreys, Harold: 1929, "The Earth," Cambridge Univ. Press, p. 154.

[2] Jeffreys, Harold: 1941, "The Thermal State of the Earth," Amer. Jour. Sci., Vol. 239, pp. 825-35.

[3] DeLury, J. S.: 1933, "The Strength of the Earth," Jour. Geol., Vol. XLI, pp. 748-56; 1936, "Geologic Deductions from a Thermal Equation," *ibid*, Vol. XLIV, pp. 479-95.

[4] Stechschulte, V. C.: 1936, "Geological Implications of Deep-Focus Earthquakes," Amer. Geophys. Union, pp. 81-83. Macelwane, J. B.: 1936, "Problems and Progress on the Geologico-Seismological Frontier," Science, Vol. 83, pp. 193-8. Gutenberg, B., and Richter, C. F.: 1939, "Evidence from Deep-Focus Earthquakes," Internal Constitution of the Earth, Chap. XI.

that the causes of these plutonic quakes are probably the same as for those of shallow origin. If so, rocks in general have great strength into depths greater than 700 kilometers. Strength in these great depths seems to imply either that even the lowest estimates of temperature in these regions are too high, or that compression dominates heat in deciding strength in these levels.

Notwithstanding these more direct thermal and seismological evidences that the crust is thick and strong, many hypotheses accept the limitations placed by the isostatic assumption of a relatively shallow shell of weakness. The writer has discussed elsewhere the evidences on which this assumption is built and reached the conclusion that they do not compel acceptance.[5] Without the shell of weakness in shallow levels no source seems to be permitted for permanent or inherited bodies of magma, hence search must be made for the means of local liquefaction. The compositions of abundant intrusives further suggest that these means operate in the outermost shells of the earth.

There seem to be definite possibilities for the local generation of important quantities of mechanical heat in the crust. The outer lithosphere is always suffering adjustments which imply the movement of large masses against the resistance of others. This, in turn, requires the generation of heat from friction. However, deformational processes are usually so slow that heat generated in this manner might be dissipated too rapidly by conduction to permit melting. This, more than any absence of important frictional heat, probably accounts for the lack of signs of true melting along fault planes near the surface. Other things being equal, such signs are expected more as depth increases, since insulation and higher temperatures are both consequences of deep burial and would facilitate melting. Furthermore, it is not unlikely that the occurrence of an important igneous mass formed from melting along a fault plane would be interpreted as a post-deformational intrusive. The same interpretation would be still more likely if the liquefied rock were forced to migrate into new positions.

In the following attempt at a solution of the problem of magma sources the writer accepts the view, as dictated by the preferred evidences, that a crust with a thickness of at least 700 kilometers has strength enough to resist large stress dif-

[5] 1942, "Compression Creep of Rubber and Rock," Jour. Geol., Vol. L, pp. 189-99.

ference during long geologic intervals. Material below the crust, owing to higher temperature, may be relatively weak and incapable of resisting stress difference of the same magnitude. Accordingly, the problem must be faced of accounting for the persistent development of magmas in outer levels where thermal and other evidences seem to decree a general lack of inherited magma.

Movements in the lithosphere are regarded as being caused primarily by thermal distortion. Failure of the crust in the thermal contraction theory will be treated as a protracted and piecemeal operation, involving the horizontal movement of enormous layers of rock over other masses. Frictional heat derived in these movements will probably generate thin layers of magma under wide regions. Following the initial formation of magma in sheets, further generation is expected from additional frictional heat derived from the energy of regional subsidence of over-riding crustal layers. The key to the present attempt to explain magma origin was provided by a recognition of the importance of compression creep in solids.

COMPRESSION CREEP INVOLVED WITH CRUSTAL FAILURE.

The movements commonly indicated by earthquakes now taking place along different parts of a widely extended fault plane indicate not only the continuous development of deforming stress in the strong crust, but also by their slowness the operation of compression creep. This operation requires only a fraction of the force needed to effect simultaneous movement along all parts of the fault. In a recent paper[6] the writer described compression creep and pointed out some of its bearings on geological processes. A quotation from this source will serve as a definition:

"A compressible solid may overcome resistance to its bodily movement by a piecemeal operation if the mass involved has dimensions permitting sufficient linear compression. Because resistance, such as friction, may be overcome locally and in successive stages, a small fraction of the force needed for an immediate effect will, given enough time, bring about the same bodily movement. This slow kind of movement against outside resistance, named 'compression creep,' suggests the view that the rate of geological deformation is correlated better with small forces operating through long time, than with mighty forces in critical periods."

[6] "Compression Creep of Rubber and Rock," loc. cit.

Measured by ordinary standards major deformation is a slow process even in the critical periods of geology. Slowness of deformation suggests control of the operation by compression creep. Accordingly, it seems that the crust of the earth may fail piecemeal in a long period of time when subjected to a stress difference small in comparison with the one required to produce instantaneous failure.

The causes of the stress differences that lead to crustal failure are none too clear, but heat seems to be the most probable and certainly the greatest source of energy available for earth movements. Appeal will be made accordingly to thermal distortion. This may arise from such things as unsymmetrical distribution of heat sources like radioactivity, and inequalities of heat conduction, but the most commonly accepted and obvious cause lies in thermal contraction of the earth as a whole. The principle of compression creep will now be applied to the problem of the failure of a thick crust in the thermal contraction theory.

FAILURE OF THE CRUST IN THE THERMAL CONTRACTION THEORY.

If the earth loses sufficient heat, contraction leads to the building up of enough horizontal compressive stress to cause failure in the crust. It is customary to assume that during a few hundred million years this compressive stress is slowly built up and that the crust fails as a whole in a relatively brief and critical period of deformation at which time the stress is largely relieved. The writer offers a contrary view that crustal failure is a very protracted process which involves much of the time usually regarded as being antecedent to failure. The possibility that the crust fails as a unit is more credible if it is assumed to be only a few tens of kilometers thick, but even here it is doubtful. With a thick crust, one 700 kilometers or more thick as the writer accepts, failure as a unit is incredible and could be admitted only on the assumption of incompressibility.

Another commonly held part of the thermal contraction theory is that contraction of the interior and a growing horizontal compression in outer layers lead to a surface of no strain between. The writer offers the contrary opinion that except with an incredibly thin crust compression dominates so com-

pletely any conceivable thermal effects in determining volume that a wide surface of no strain is impossible. Volume compression is characteristic of all parts of the earth except in shallow levels where deformation may lead to local tension.

Measurements[7] show that granitic rocks are more compressible than those of gabbro composition which are supposed to prevail in a lower shell. Similarly, gabbro is more compressible than olivine-rich rocks which probably assume dominance in still deeper levels. The same measurements further establish what is expected on theoretical grounds, namely, that rocks become less compressible with increasing compression. Taken together these evidences point to an important and continuous decrease of compressibility from the surface downward. Seismological data on the elastic properties of rocks in various depths give confirmation. It is gathered from B. Gutenberg's estimates[8] of the variation of elastic constants in depth, that the outer granitic layers have several times the linear compressibility of material near the 700-kilometer level. With this difference in linear compressibility from top to bottom and with other things equal, the crust would be expected to fail first in lower levels from the horizontal compression built up by thermal contraction. However, other controlling factors are not equal. For example, strength probably increases into great depths and may do so in a degree that would offset differential compressibility in deciding the manner of failure. Again, temperature changes may be a considerable factor in determining the linear compression of various layers, owing to their influence on volume. Exact appraisal of all controlling factors in failure is impossible, but it seems very improbable that these will ever be so nicely balanced that the entire crust will fail as a unit. Other and perhaps the decisive factors suggest that the lower crustal layers fail first and that the greater and lower part of the crust fails inward before a relatively shallow outer shell is seriously taxed by the horizontal compressive stress.

Loss of heat from subcrustal regions, that is to say below depths of 700 kilometers or thereabout, leads to reduced volume compression in those regions and to concurrent horizontal compression in the crust. The force of gravity now acts to

[7] Adams, L. H.: 1939, "Elastic Properties of Materials of the Earth's Crust," Internal Constitution of the Earth, Chap. IV.

[8] 1939, "The Elastic Constants in the Interior of the Earth," Internal Constitution of the Earth, Chap. XIV.

"shorten" the crust. The first effect expected is an elastic downwarping of susceptible parts of the crust, an effect which is essentially the same as that viewed in the dimpling of a hollow rubber ball when inside compression is reduced by partial deflation. This dimpling would be impossible in the crust if rocks were incompressible but in the long circumference of the earth there is a degree of compressibility that permits a reasonable comparison with the rubber ball. The areas of downwarping would likely be determined largely by crustal thinness, though other factors might contribute. The various geosynclinal depressions of geologic history may well be initiated by and reflect this elastic downwarping which is expected as the first effect of thermal distortion. The existence of geosynclines may be determined accordingly by the same influences that later lead to crustal failure. If so, support is given to a view to be developed later that crustal disturbances from thermal contraction occupy a large part of the long period involved in the building up of horizontal compression to the time of its final release. An initiation of geosynclines in this manner would also support the view that the relations between their locations and those of final folding are decided in an early stage by common causes.

The expected initial effect of thermal contraction on the crust, namely elastic downwarping, leads to a lessening of the area of the crust, since the crustal arch is flattened across wide geosynclinal belts, and hence to an increase in the horizontal compressive stress. The time required for ultimate failure is accordingly shortened. With further thermal losses and accompanying downwarping the time comes when the crust must fail. It has been indicated already that general factors suggest that the thick crust will not fail as a unit, but successively in its different parts as these are affected by the controls over failure. Next to be examined are the particular conditions set up by thermal contraction, which may determine the manner and place of initial failure.

Reduction of cubic compression in subcrustal regions leads to a lessening of the support for the lowest and relatively incompressible layers of the crust, which are expected to fail before shallower layers of more compressible material. Other and local conditions might contribute to determine the place of initial failure. For example, elastic downwarping might cause a local and pronounced increase of horizontal compres-

sion. This would suggest a possible correlation of the sites of geosynclines and those of initial crustal failure. Again, the place of failure might be associated with unevenness in thickness of the crust. Thermal considerations support the view that the crust is thicker under ocean basins than under continents.[9] This being so, and with the reduced pressure in subcrustal regions, ideal conditions are offered for the intervention of failure by compression creep. Unevenness in the bottom of the crust would influence the location of the place of first failure brought about by differential compressibility perhaps long before the strength of overlying layers is taxed. Failure of the crust may begin accordingly, shortly after the initiation of geosynclinal depressions and long before the final failure as viewed in shallow deformation.

A low-angle underthrust fault displacement is started in the bottom of the crust. A favorable place for failure is provided by proximity to a belt of elastic downwarping and to a region where the thicker oceanic crust gives way horizontally to the thinner sub-continental crust. Reduced volume compression in subcrust and consequent lessening of lateral support for the downward bulge of the sub-oceanic crust would provide conditions that favor the "slicing" off of the bulge through the operation of compression creep. A fault plane starts to form near the flank of the bulge and slowly extends at a low angle to embrace a wide belt of the lower crust. The lower part of the oceanic crust is slowly underthrust into the subcrustal region of reduced compression. The amount of linear compression in the underthrusting layer will probably require a movement of a kilometer or more along much of the fault plane, which may be gradually extended thousands of kilometers horizontally. Plutonic earthquakes will accompany the movement and heat from friction will be developed in enormous quantities. Heat would cause liquefaction along the fault plane if movement were rapid enough. On the other hand, if movement were sufficiently slow, no melting would result, but the similar quantity of heat developed would lead to thermal expansion of rocks above and below the fault plane.

When the horizontal compressive stress is released from the bottom shell, this layer becomes a part of the subcrust in the sense that it joins the region governed by volume rather than linear compression. Owing to the vagueness of quantitative

[9] Jeffreys, H.: 1935, "Earthquakes and Mountains," p. 164.

data the writer sees no means of approaching an estimate of the thickness of the shell involved in the initial failure. It may be a thick shell representing a large fraction of the crustal thickness or it may be a relatively thin shell. If the latter, it seems likely that the bulk of the crust will be involved in a succession of failures of a number of layers from the bottom outward. Each failure would be accompanied by plutonic earthquakes and important heat generation. Whatever the manner of failure, the sum of expected effects is that the relatively incompressible bulk of the crust accommodates itself to horizontal compression by underthrust faulting. Moreover, this compressive stress is largely released before the more compressible outer shell of rocks has its strength seriously taxed by the same compression.

Eventually the more compressible outer shell of the earth must succumb to the great horizontal stress induced by thermal contraction. When it yields it will act as a unit and its various parts will migrate differentially over deeper rocks which have lost most of the horizontal compression. The common estimate from data on the strength and compressibility of abundant rocks is that the crust suffers a circumferential shortening of 40 to 50 kilometers before failure is required.[10] Other factors may reduce this estimate. However, the linear compression in the outer shell is of a magnitude to require that when failure ensues, movements of the outer shell toward the places of failure will be through distances of at least a few kilometers. The thickness of this outer shell is problematic and is probably variable in time and place. The initial failure is expected to be near the surface along a low-angle overthrust fault. The first movement will be relatively rapid. Later movements, controlled by compression creep, will be slower. The overthrust fault plane will be gradually extended and will become more and more horizontal. Eventually it will reach the bottom of the compressed outer shell, along which it is expected to grow horizontally until the compressive stress is largely relieved from the entire shell. Wide regions are accordingly involved. The frictional heat developed in the forced sliding of a thick sheet of outer crust over a now static lower crust is looked on as a probable means of producing magma in shallow levels. An attempt is made in

[10] Jeffreys, H.: 1935, "Earthquakes and Mountains," p. 145.

Fig. 1 to give diagrammatic expression of the mechanism which has been described.

GENERATION OF MAGMA FROM FRICTIONAL HEAT.

Failure of the outer shell of the crust in the manner described implies the movement through several kilometers of enormous masses of unknown but considerable thickness which cover areas equal to a large fraction of the earth's surface. Heat must be developed in enormous quantities along a nearly horizontal fault plane. P. G. Nutting[11] provides a formula for the estimation of heat generated in overcoming friction

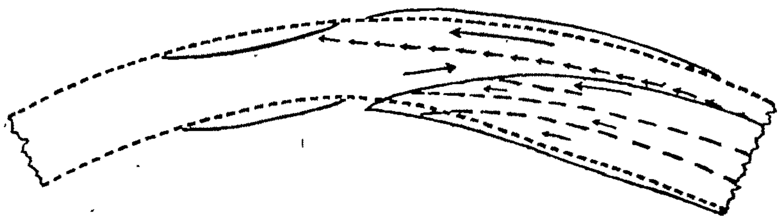

Fig. 1. Section of the earth's crust about 6,000 kilometers long and from 600 to 800 kilometers thick. The thinner continental crust to the left shows elastic downwarping in the change from the broken to the solid lines. A continuation of the broken lines into the region to the right depicts the thicker sub-oceanic crust before deformation. The underthrust portion of the major and deeper part of the crust is surrounded by solid lines. The same total effect might be produced by a number of underthrust slices suggested by the broken lines in the same portion. The later overthrust of the outer and lesser part of the crust is indicated by the long arrow. The underlying row of arrows marks the bottom of this overthrust slice, and at the same time shows the horizon in which magma is expected to be formed from frictional heat. Change in elevation at the surface, brought about by thermal expansion and perhaps by crustal thickening due to underthrusting, is suggested by the change from the broken to the solid line over the region to the right. The scales of downwarping, of thermal expansion and of the thickness of the outer, overthrust layer are exaggerated.

between rock surfaces. Following his data, a rock layer thick enough to exert a pressure of 1,000 pounds per square inch, when displaced a distance of 1 centimeter horizontally over a similar rock surface, develops 0.33 calorie for each square centimeter of the frictional surface, or enough heat to raise the temperature of a layer of ordinary rock 1 centimeter thick 0.8 degrees C. If this formula were applicable for the horizontal displacement through 1 kilometer of an outer shell 60 kilo-

[11] 1929, "Deformation and Temperature," Jour. Wash. Acad. Sci., Vol. 19, pp. 109-15.

meters thick, a rough calculation would show the generation of enough heat to warm and melt a thickness of more than 200 meters of common rock. This result is valuable for showing the potentialities of frictional heat in great earth movements, but the formula does not apply after melting is started. Other equations for determining mechanical heat would then be necessary, such as those used for viscous or plastic flow.

The rate of the horizontal displacement of the outer crustal layer has a decisive influence in determining the amount of heat available for magma generation. Rapid movement would cause a sudden generation of magma and then only heat from friction in viscous flow would be available. In the same rapid movement the latter source becomes increasingly small with the decreasing viscosity following rise of temperature. If movement were slow enough, on the other hand, frictional heat would be removed by conduction and magma generation prevented. That movement may be too slow to allow frictional heat to overwhelm losses by conduction is shown by the absence of magma in extensive overthrust fault planes in shallow levels. However, projection of these same places into distant and deeper regions might well spell magma generation. Deformation is slow, even in critical periods, so that the thermal insulation provided by burial to depths of a few tens of kilometers becomes an important factor.

With the failure of the outer shell local movement near the place of failure is expected to be relatively rapid. Magma will form and resistance to compression creep accordingly will be lessened in more distant areas, so that the fault plane is extended and the sheet of magma expands more or less in pace. Various conditions surround different parts of the fault plane. In one place melting may be resulting from solid friction. In another heat may be generated in viscous flow or even in plastic flow of highly heated material. Except locally and during brief periods it seems unlikely that viscosity will be so low that considerable heat will not be produced in viscous flow. Slow movement favors the formation of much highly viscous material rather than of small quantities of superheated liquid. Moreover, viscosity is known to increase enormously under confining pressures expected at depths of a few tens of kilometers. A displacement effected through flow in highly viscous material will probably produce a large fraction of the heat expected

when the movement is effected against solid friction. It appears accordingly that there are great potentialities for magma generation along deep fault planes.

With the establishment of a widespread sheet of magma beneath the creeping outer shell of the crust, fresh possibilities arise for the creation of further important quantities of magma from the heat of friction. It was indicated in earlier pages that the heat generated along the widely extended underthrust fault or faults is expected to cause notable thermal expansion of the thick crust both above and below the levels of failure. It was suggested also that elevation of the surface might result from thickening of the crust due to underthrusting. A rough estimate will show, however, that the thermal effect alone is probably sufficient to cause a surface elevation of a few hundred meters. This elevation implies the creation of a "head" above the level in which magma is later formed by creep of the outer crustal layer. A wide region, corresponding to a large fraction of the earth's area, if it has a "head" over surrounding regions and overlies a more or less continuous sheet of magma, will tend to subside and to drive the magma horizontally into surroundings with lower "head." The energy of subsidence is enormous and a small fraction of it converted into heat would account for the generation of great quantities of additional magma. The mechanical equivalent of heat from subsidence of a layer about 60 kilometers thick through a distance of 100 meters is roughly equal to the amount needed to melt a layer of rock 180 meters thick or to warm and melt a cool layer 80 meters thick. It is not implied that all this heat is available for melting. However, with the degree of viscosity expected at great depth and in company with slow movement a large fraction of this mechanical heat may well be expended in the generation of additional magma.[12]

SUMMARY OF HYPOTHESIS AND AN INDICATION OF ITS BEARINGS ON GEOLOGICAL PHENOMENA.

Thermal and seismological evidences of strength into depths of several hundred kilometers suggest not only a crust of corresponding thickness but that the earth is a cooling body as well. A cooling earth will suffer two kinds of thermal distortion. One of these leads to crustal failure and results from

[12] DeLury, J. S.: 1932, "Magmas from Subsidence," Amer. Jour. Sci., Vol. XXIII, pp. 357-68.

symmetrical cooling by more or less equal conduction along all radii and a consequent volume shrinkage. Another kind of distortion is possible from exceptional and local heat losses or gains which may be reflected at the surface by changes of elevation. Stresses caused by thermal contraction lead to failure and require the movements of large masses of the crust against others and the consequent generation of important quantities of frictional heat. In the manner of failure predicted for the crust, the outer layer of considerable thickness is displaced horizontally through a distance of several kilometers against the friction of underlying rock. The frictional heat developed in this displacement causes liquefaction and the formation of a widely disposed sheet of magma. Subsidence of the overlying layer leads to the generation of more frictional heat and an increased quantity of magma. A generation of magma in this manner in the shallower levels of the crust meets fairly the abundant compositional evidence that the largest masses of igneous rocks seem to come from magmas derived in these levels. There is accordingly no need to appeal to differentiation of deep and inherited sources of magma to account for the formation of the abundant granite batholiths.

In attempting to apply this hypothesis of crustal failure to an explanation of outstanding geologic events the many conflicts of view in the field of tectonics present themselves. Space permits only a brief indication of its possible application to some of the major tectonic problems.

In drawing Fig. 1 the writer had in mind the history of the Appalachian region. Downwarping without failure initiated the geosyncline, which during the Paleozoic era received a thick accumulation of sediments. An extensive borderland to the east, which supplied the bulk of these sediments, is related to the elevation caused by thermal expansion as shown in the Figure. When the outer layer of the crust failed, it moved against the weak sedimentary layers of the geosyncline and deformed them. With subsidence of the borderland great quantities of magma were generated to move horizontally and finally upward to form the batholithic core of the folded Appalachian mountains. This succession of events on the Atlantic side of North America is fairly typical of the processes by which the continental mass has been narrowed and thickened into a relatively high-standing continent. However, the movements which Asia has suffered in the later geologic eras have opposite

effects. Apparently this continent is spreading outward. Accordingly, the mechanism of crustal failure is different under various regions. Other factors than those described in earlier pages and indicated in Fig. 1 may decide places of downwarping and whether movements will be toward continents or ocean basins. Again, a modification of the manner of failure described may govern in oceanic areas.

In most mountain systems there is good evidence that the thrust which leads to "shortening" comes mainly from one direction. The present hypothesis seems to offer a reasonable explanation of this phenomenon, which presents obvious difficulties in the opposing concept of a relatively thin crust collapsing as a unit. Perhaps the most serious criticism that has been levelled at the thermal contraction theory of crustal failure comes from the evidence that the amount of crustal "shortening" is too great to be explained by the theory. A related objection arises from the indications that important tensional effects, like normal faults, are produced more or less contemporaneously with compressional effects as viewed in folding and overthrusting. In other words, the crust is "lengthened" in some regions while being "shortened" in others. The writer's hypothesis offers definite possibilities for the removal of these difficulties.

Regional subsidence of an outer crustal layer creates magma and drives it forcefully into shallow mobile belts. Differential drag by the moving and viscous magma sheet may carry parts of the layer faster than others, leading to compressional effects in the mobile belt at the front and to contemporaneous tensional effects, such as stretching and normal faulting, in a wide region to the rear. The forceful intrusion of magma accordingly produces effects which may give an exaggerated impression of the amount of crustal "shortening."[13] Similar effects are produced by differential flow in continental ice sheets and by the migration of rock salt from beds to form salt domes.

The manner of failure indicated for the deeper part of the thick crust suggests an explanation of plutonic earthquakes. In fact, these quakes supply the best evidence as to the thickness of the crust. They are expected in all levels between those of "normal" depth down to 700 or more kilometers. It is further anticipated that the "sense" of direction of movement will be the same under wide regions and throughout long

[13] DeLury, J. S.: "Magmas from Subsidence," *loc. cit.*

periods of time. In general, shallow quakes above the same regions are expected to show movement in an opposite "sense."

Further possible applications of the hypothesis can be barely indicated at this time. For example, it suggests an explanation of diversification of igneous rocks by mixing processes rather than by differentiation. Intrusion is forceful in the main, though local effects may suggest that it is passive. The suggested correlation of deformation and intrusion agrees with the facts. The "sial" of continental masses is segregated by horizontally rather than vertically operating processes. Hence comes a plausible explanation of vast geographic changes and the baffling problem of past continental connections and separations. Adequate means are suggested for changes of elevation. A fairly even distribution of mass around the earth is expected, but there is also room for the creation of important gravity anomalies. Confusion is added to the already confused thermal problem of the earth, but may lead eventually to its clarification.

The writer has avoided any attempt at minute accuracy in estimates of distances of displacement, of quantities of heat, etc. Data are too inaccurate to permit the use of anything but round numbers. However, the hypothesis is regarded as being on a sound qualitative and a reasonable quantitative basis.

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A CARBONIFEROUS FLORA FROM THE WAMSUTTA FORMATION OF SOUTHEASTERN MASSACHUSETTS

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ABSTRACT. A few years ago a fossil flora was found in the Wamsutta red beds at South Attleboro, Massachusetts. The fossils apparently located in the upper part of the formation include ferns and other plants not previously reported in these beds. They demonstrate that the upper part of the Wamsutta is contemporaneous with the Rhode Island formation, as suggested by Woodworth. The age of this flora is probably lower Allegheny.

INTRODUCTION.

THE Wamsutta formation of southeastern Massachusetts and northeastern Rhode Island consists mainly of interbedded red shales, sandstones, and conglomerates considerably folded and faulted. Stratigraphically these beds locally underlie the Rhode Island Coal Measures of Pennsylvanian age, and in other places are interstratified with them. It was the opinion of J. B. Woodworth[1] that the Wamsutta is contemporaneous with the lower part of the Rhode Island formation.

The relationship of the Wamsutta formation to the other rocks in the northern part of the Narragansett Basin is shown in the following table largely based upon the stratigraphical studies of Shaler, Woodworth, and Foerste.[2]

Edward Hitchcock[3] and C. H. Hitchcock[4] both considered the Wamsutta to be Devonian or equivalent to the Old Red Sandstone; others considered these rocks to be Silurian and even Triassic. Logan and Hall,[5] however, mapped them as Carboniferous. The discovery by Foerste[6] of Calamites impressions in red shales at North Attleboro, Massachusetts in 1887 definitely proved that the red beds in this area at least are of Carboniferous age. Besides *Calamites* a *Cordaites* was found in these beds, and probable *Sigillaria* and *Calamites* were dis-

[1] Woodworth, J. B., N. S. Shaler, and A. F. Foerste: 1899, Geology of the Narragansett Basin, U. S. Geol. Surv. Mon. 33, p. 159.
[2] Op. cit., p. 184.
[3] Hitchcock, E.: 1841, Final report on the geology of Massachusetts.
[4] Hitchcock, C. H.: 1871.
[5] Logan and Hall: 1865, Geological Atlas.
[6] Op. cit., pp. 141, 158.

TABLE 1.

Stratigraphical succession of the rocks in the northern part of the Narragansett Basin.

Pleistocene and Recent		Glacial, lake, and marine deposits
Unconformity		
Carboniferous	Dighton fm. (Cd) (1,000-1,500 feet)	Conglomerates and sandstones
	Rhode Island fm. (Cc) Coal Measures (10,000 feet)	Westville shales
		Seekonk sandstones and conglomerates
		Tenmile River sandstones and shales
		Mansfield coal beds
		Cranston coal beds
		Sockanasset sandstones and conglomerates
		Pawtucket shales
	Wamsutta fm. (Cw) (1,000 feet)	Shales, sandstones, and conglomerates, mostly red in color, with interbedded felsites, melaphyres, and some limestone
	Pondville fm. (Cp) (100-500 feet)	Conglomerates and arkose
Unconformity		
PreCarboniferous		Granite, Cambrian and pre-Cambrian sediments

covered in rocks considered to be Wamsutta further north in the Norfolk Basin.[7]

Besides plant fossils, amphibian footprints have been reported from the red beds in the vicinity of South Attleboro, Massachusetts.[8]

These fossil remains, however, are so scarce and so poorly preserved that outside of determining the age as Carboniferous they cannot be used as horizon markers or for determining

[7] Crosby, W. O., and G. H. Barton: 1880, Extension of the Carboniferous formation in Massachusetts, Amer. Jour. Sci., 3d Ser., Vol. 20, pp. 416-420.
Woodworth, J. B.: 1894, Carboniferous fossils in Norfolk County Basin, Amer. Jour. Sci., 3d Ser., Vol. 48, pp. 145-148.

[8] Willard, B. and A. B. Cleaves: 1930, Amphibian footprints from the Pennsylvanian of the Narragansett Basin, Bull. Geol. Soc. Am., Vol. 41, pp. 321-327.

the relationship of the beds in which they occur to the Coal Measures proper.

A few years ago a new fossil plant locality was discovered in the Wamsutta beds in a road cut at South Attleboro, with a flora that has an important bearing on the relationship of these beds to the Rhode Island formation. The flora consists of several species of identifiable plants, including ferns, not previously reported from these beds. The study of this flora showed that Woodworth was correct in considering the Wamsutta, at least in part, contemporaneous with the lower part of the Rhode Island formation further to the south.

THE FOSSIL LOCALITY.

The locality from which the Wamsutta flora described in this paper was obtained is near the town of South Attleboro about two miles south of Hoppin Hill in a road cut along Route U. S. 1 (latitude 41° 56⅛′, longitude 71° 21′), in the same region where the amphibian tracks were discovered. The section of red rocks here exposed is as follows north to south:

Section through fossiliferous rocks at South Attleboro.

	Feet
Concealed northward	
Coarse sandstone	9
Conglomerate	11
Sandstone	6
Conglomerate	11
Shale with fossil plants	2
Sandstone	7
Conglomerate	20
Concealed southward	
Total	66

Although these beds show considerable cross bedding the general dip is about 35° to the northwest. A study of the outcrops in the vicinity revealed that the horizon at which the fossil plants were found is stratigraphically several hundred feet below the top of the formation and above the felsite flows outcropping in the vicinity. It appears to be somewhat about the middle of the Wamsutta series exposed in this region.

The following is a list of the fossil plants found here:

Annularia stellata (Schl.) Wood
Calamocladus longifolius (Stb.) Brgt.
C. equisetiformis (Schl.) Brgt.
Calamites suckowi Brgt.
Pecopteris sp.
Neuropteris cf. N. rarinervis Bunb.
Sphenopteris valida Daws.
Sphenopteris sp..
Oligocarpa splendens Daws.
Cordaites cf. C. robbii Daws.
Cordaites cf. C. communis Lx.
Sigillarian leaves

These fossils are practically all restricted to the bed of red shale. Although a careful search was made for fossils in the associated beds and other outcrops in the vicinity, only traces were found.

There is very little carbonaceous material present, the remains of the plants being mostly impressions of stems and leaves. The more delicate fossils would be easily overlooked except for the fact that the carbonaceous material that was originally present has bleached the sediments and as a result the impressions in many cases are lighter in color than the surrounding matrix.

At the base of the shale layer impressions of *Cordaites* leaves are extremely abundant. Higher up the fossils are less common, but the remains of leaves and stems of *Calamites* together with ferns and other plants are of frequent occurrence. It was noted that some of the leaf bearing branches of *Calamocladus* extended for several inches through the shale at right angles to the bedding. A cast of a *Calamites* stem was found which extended directly upward from the shale into the overlying conglomerate.

The distribution of the plant remains warrants the assumption that they grew at or close to the place of burial. The delicate character of some of the ferns precludes the possibility of these remains having been transported any great distance. Furthermore the upright position of a number of the fossils indicates not only that they are *in situ* but that burial was rapid.

Associated with the fossils in the upper portion of the shale layer are occasional red clay concretions or mud balls

ranging in size from one to three inches in diameter. They contain no calcareous material and there are no apparent nuclei about which they might have formed. The color and texture of these masses are the same as those of the shale in which they are imbedded. Most of them have growth layers as if they had been formed by being rolled along over a soft clay bed. Some showed evidence that two or more of these masses had coalesced during their formation.

These facts together with the changeable character of the sediments, the presence of cross bedding, current marks, occasional rain drop impressions and mud cracks, amphibian tracks, and the complete absence of marine fossils suggest that the Wamsutta formation is in part a piedmont deposit on which were local temporal ponds and marshes where plants were able to grow for a time until destroyed by flood conditions. This idea would account for the scarcity and localized occurrence of fossil remains in these beds.

THE RELATIONSHIP OF THE WAMSUTTA BEDS TO THE RHODE ISLAND COAL MEASURES.

The presence of red beds interstratified with carbonaceous sediments of the Rhode Island Coal Measures along the margins of the main areas of the Wamsutta formation in Massachusetts and Rhode Island led Woodworth to believe that the Wamsutta was in time equivalent to the lower part of the Rhode Island formation. Around Pawtucket, Rhode Island, the Coal Measures are stratigraphically below the red beds, but south and west of this area the red rocks disappear in the coal bearing sediments.[9] From these relationships Woodworth considered that the Pawtucket shale, apparently near the base of the Rhode Island formation, is in position lower than the southern continuation of the Wamsutta beds.

The relationship of the Wamsutta to the Rhode Island Coal Measures as interpreted by Woodworth is shown in Fig. 1.

The fossil plants from the Wamsutta red beds at South Attleboro seem to indicate that this interpretation in the main is valid. Although the number of species so far found in this formation is small compared to those in some of the beds of the Rhode Island Coal Measures, they are numerous enough for correlation.

[9] Shaler, Woodworth, and Foerste: op. cit., pp. 147-148.

TABLE 2.

Distribution of the Wamsutta flora in the Rhode Island formation, and in New Brunswick and Missouri.

	Pawtucket	Valley Falls	Cranston	Sockanosset	Tunnel, Providence	Warwick	Boyden Heights	Silver Springs	E. Providence	Bristol	Warren	Portsmouth	Castle Rock	Newport	Perrins, Mass.	Mansfield, Mass.	Fern Ledges, N. B.	Henry Co., Mo.
Annularia stellata (Schl.) Wood	×	×	×		×					×		×		×		×	×	×
Calamocladus longifolius (Stb.) Brgt.		×												×				×
C. equisetiformis (Sch.) Brgt.	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×
Calamites suckowi Brgt.	×	×						×							×		×	×
Neuropteris rarinervis Bunb.		×						×				×						×
Sphenopteris valida Daws.		×															×	
Oligocarpa splendens Daws.		×										×					×	
Cordaites robbii Daws.	×																×	
Cordaites communis Lx.		×													×			×
Sigillarian leaves	×																	×

Table 2 shows the distribution of the fossil plants of the Wamsutta in the Rhode Island formation as determined by Dr. Edna Round.[10] It is immediately apparent that the flora from South Attleboro is strikingly similar to those from the Pawtucket shales of Valley Falls, a suburb of Pawtucket, and Pawtucket proper. Of the ten probable species from the Wamsutta, eight are found at Valley Falls, while five are from Pawtucket. Of the remaining localities where Rhode Island Carboniferous plants occur, the great majority have less than three species common to the red beds, although they include some of the most productive fossil plant areas.

It seems from these facts that the horizon from which the

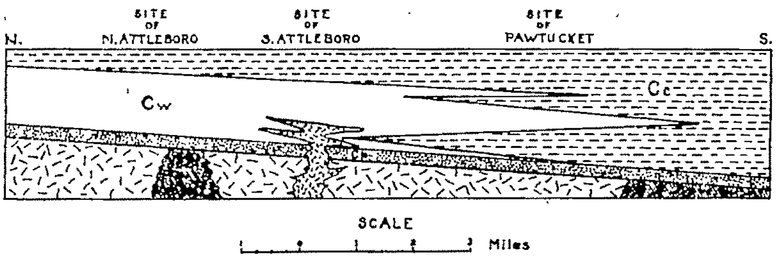

Fig. 1. Relationship of the Wamsutta formation (Cw) to the Rhode Island formation (Cc) in the vicinity of Pawtucket, R. I. Cp, Pondville conglomerate. Modified after Woodworth.

fossils were obtained in the Wamsutta is approximately of the same age as the Pawtucket shales and that the upper part of the Wamsutta formation is contemporaneous with the lower part of the Rhode Island Coal Measures. However, it is questionable whether or not the entire series of red beds is in time equivalent to the Rhode Island formation.

At Plympton, Massachusetts, at the extreme eastern margin of the Coal Measures, there is an area of felsite similar to that found in the Wamsutta beds around North Attleboro and Diamond Hill, Rhode Island.[11] Although their relationship

[10] Round, E.: 1924, Correlation of the fossil floras of Rhode Island and New Brunswick, Bot. Gaz., Vol. 78, pp. 116-118.

————: 1927, Correlation of coal floras in Henry County, Missouri, and the Narragansett Basin, Bot. Gaz., Vol. 83, pp. 61-69.

[11] Eaton, H. N.: 1925, Structural relations of the igneous rocks of the Wamsutta red beds, Massachusetts (Abs.), Geol. Soc. Am. Bull., Vol. 36, pp. 165-166.

to the Carboniferous sediments is obscure, Woodworth interpreted this to mean that the outflowings of felsite occurred about the same time that the first Carboniferous sediments were being deposited in this area.[12] He noted the similarity of the occurrence and character of these felsites to those around Boston and suggested that they may be of the same age.

Around South Attleboro the felsites in the Wamsutta came after the deposition of the Pondville conglomerate and after the red beds had begun to accumulate, but before the appearance of the Coal Measures in this section of the basin. It thus appears that the lower part of the Wamsutta may be of the same age as the lowermost beds of the Rhode Island formation or it may be somewhat older.

AGE OF THE WAMSUTTA FLORA.

Doctor Round has noted the similarity of the species of plants found in the Rhode Island Coal Measures to those of the Fern Ledges of New Brunswick, and the Cherokee shales of Missouri.[13] It is noted that some of the most common and widespread species in the Rhode Island formation are commonly found in the Fern Ledges. These New Brunswick beds have been considered to be Pottsville,[14] although Stopes[15] believes they are somewhat higher and equivalent to the lowest zone of the middle Westphalian of Europe, or the lower Allegheny in the eastern part of this country.

On the other hand over 50 per cent of the species found in the Rhode Island area are common to the Cherokee shales of Missouri of lower Pennsylvanian age. These were thought by White[16] to be equivalent to the upper Westphalian of Europe, or the middle and upper Allegheny in eastern United States. According to the most recent data[17] the Cherokee is considered to be lower Allegheny and late Pottsville. It thus appears that the Rhode Island Coal Measures in general are probably

[12] Shaler, Woodworth, and Foerste: op. cit., pp. 116, 155.

[13] Op. cit.

[14] White, D.: 1901, Some botanical aspects of the Upper Palaeozoic in Nova Scotia, Can. Rec. Sc., Vol. 8, pp. 271-280.

[15] Stopes, M. C.: 1914, The Fern Ledges, Carboniferous flora of St. John, N. B., Can. Dept. Mines, G. S., No. 88, Memoir 41, pp. 1-142.

[16] White, D.: 1899, Fossil flora of the Lower Coal Measures of Missouri, U. S. G. S. Mon. 37, pp. 1-307.

[17] Schuchert, C.: 1943, *Stratigraphy of Eastern and Central United States*, New York and London, p. 687.

lower or middle Allegheny, and that the upper part of the Wamsutta red beds from which the fossil plants were obtained and which appears to be equivalent to the lower part of the Rhode Island Coal Measures, is most likely to be from the data at hand of lower Allegheny age.

ACKNOWLEDGMENTS.

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THE PERMIAN COTYLOSAUR DIADECTES TENUITECTUS.

ALFRED SHERWOOD ROMER.

ABSTRACT. A skeleton of the Permian reptile *Diadectes tenuitectus* from the Clear Fork group of Texas is described and figured, with particular regard to the atlas-axis complex and the fused astragalo-calcaneum.

THE anatomy of the Permo-Carboniferous reptile *Diadectes* is well known in many regards, due to the work of Cope, Case, Williston and other writers. Most of the material described, however, has been obtained from the lower fossiliferous beds of Texas, those of the Wichita group; little is known of the representatives of the genus in the later Texas horizon, the Arroyo formation of the Clear Fork group. The skeleton discussed below (No. 1035, Museum of Comparative Zoölogy) is from the Clear Fork and is thus not without interest.

The specimen was collected by Sternberg in 1882, during his first trip to Texas.[1] It had, however, lain unnoticed in the Harvard collections for nearly half a century until in 1929 it was rediscovered and then prepared and mounted for exhibition. It is now being remounted in panel form; this has made it both possible and necessary to inquire into its anatomy.

The exact place of collection is unknown, but it is certainly from the Arroyo formation and presumably from the Coffee Creek region of Baylor County, Texas. From this horizon were, apparently, derived all the materials collected by Sternberg at that time, and most of his finds were from Coffee Creek.

The skull is imperfect, the region posterior to the orbits having been lost except for the basioccipital region and imperfect quadrates. The jaws are nearly completely preserved. The dentition is poorly preserved, with little of the crown of the "molars" remaining. The jaw rami have a length of about 28 cm. From the guide given by the position of the jaw articulation, the length of the skull can be estimated as having been approximately 24.5 cm. Other described Clear Fork skulls are the type of *D. huenei*, which is of about the same length (25.8 cm.),[2] and the type of "*Bolbodon*" *tenuitectus* which is

[1] Sternberg, C. H.: 1909, The life of a fossil hunter, pp. 205-229.
[2] Broom, R.: 1914, Some points in the structure of the diadectid skull. Bull. Amer. Mus. Nat. Hist., XXXIII, p. 110.

28.4 cm. in length.[3] The size of these skulls is considerably above that of the other Texas diadectid skulls described from various localities in the Wichita group, as may be seen by the comparative figures on dentitions given by Broom.[4] Our specimen is presumably cospecific with *D. huenei* and this in turn with the earlier described *D. maximus*, founded on vertebrae from this horizon.[5] '*Bolbodon*" *tenuitectus* seems quite certainly to be a *Diadectes* from the same horizon, which has priority over the other two available names. The size differences are not great. The presumed specific character of *D. tenuitectus* is the thinness and lesser degree of sculpture of the cranial roof elements in that form. Because of imperfections in our skull close comparisons cannot be made; however, these features are not improbably to be associated with age and sex differences. I believe that all Clear Fork diadectid material should be assigned to *Diadectes tenuitectus* until valid specific differences are available.

Twenty-one presacral vertebrae are preserved, including several series of articulated elements, but with a number of breaks, so that the presacral count may have been somewhat higher. The sacrals are represented by their centra, and there are 11 caudals present—not, however, articulated. The centra are in general well preserved, but the neural spines are without exception broken off and relatively few are present. Typical dorsal and lumbar vertebrae average about 4.5 cm. in length; anterior dorsals are slightly shorter. The transverse diameter of mid-dorsal centra (taken at the end of the centrum) averages about 5.0 cm. The height of the vertebra to the zygapophyses is 5.6 cm. in an anterior dorsal, and 5.0 and 4.8 cm. in a typical mid-dorsal and lumbar respectively. The width across the zygapophyses in the same regions is 11.7, 10.4, and 12.8 cm.

Except for imperfect spines the first three vertebrae are preserved in articulated fashion. With spines restored and a few slight details added from other material these vertebrae are shown in Text Fig. 1. There is a facet on the atlantal neural arch for a pro-atlas, but that element is not preserved.[6] Presum-

[3] Case, E. C.: 1911, A revision of the Cotylosauria of North America. Carnegie Inst., Washington, Pub. No. 145, p. 28.

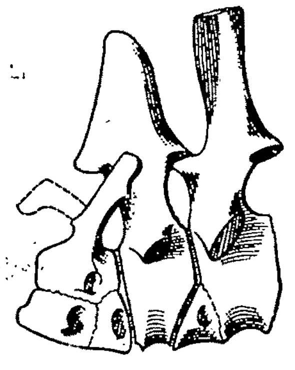
[4] Broom, R.: 1914, op. cit., p. 110.

[5] Romer, A. S., and Byrne, F.: 1931, The pes of *Diadectes*. Palaeobiologica, IV, p. 26.

[6] Cf. Olson, E. C.: 1936, Dorsal axial musculature of certain primitive Permian tetrapods. Jour. Morph., LIX, Fig. 8.

ably correlated with the maturity of the individual, there is a high degree of fusion of elements in the atlas region, in contrast to the discrete arch and centrum figured by Olson. The atlantal neural arches have the characteristic shape seen in many other early reptiles, a slender process passing backward and upward on either side of the base of the axial spine, and with a facet facing downward for articulation with that element. The base of the arch on either side is expanded, bears a distinct raised circular facet for the rib tubercle, and anteriorly forms with the adjacent intercentrum a deep subcircular socket for the skull condyle. Ventrally and posteriorly the arches are fused to a mass of bone which extends backward without break to the axis centrum and bears on either side two facets for rib attachments. It is obvious that this mass includes both intercentrum and centrum of the atlas and the axial intercentrum as well. Faint rugose lines, shown in our figure, appear to indicate the position of sutures between the elements. These, if correctly interpreted, indicate that the major ventral portion of this fused mass consists merely of the two intercentra, and that the atlantal centrum failed to reach the ventral surface of the column (cf. the pelycosaur *Ophiacodon*), being represented by only a small postero-dorsal portion of the fused mass.

As noted, the spine of the axis is not preserved. The arch



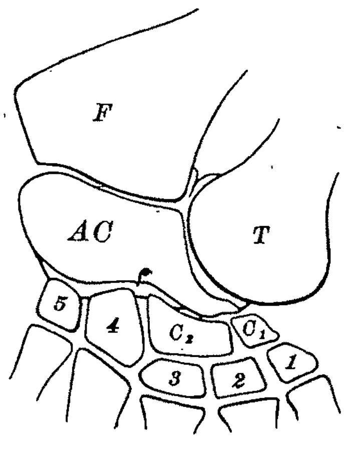


Fig. 1. Diagrammatic restoration of the first three vertebrae. x 1/6.
Fig. 2. Sketch to show assumed relations of astragalo-calcaneum (AC) to adjacent elements. The tarsals are restored as if completely ossified. C_1, C_2, Centralia; F, Fibula; T, Tibia, 1-5, distal tarsals.

bears an oval rib facet. Ventrally, the centrum is thin anteroposteriorly, with a pronounced median ventral pit at the anterior margin. The *Diadectes* axis, as noted elsewhere, is well represented by the isolated type vertebrae of *Metamosaurus*.[7] The third intercentrum is large and appears to be fused to the centrum.

A considerable amount of rib material is present, but for the most part disarticulated. Atlantal and axial ribs are present and articulated. Both are slender, although flattened and slightly dilated distally, and are distinctly two-headed. The first measures 82 mm. in length; the second is incomplete.

Of the shoulder girdle there are only fragmentary remains. The left side of the pelvis, of characteristic diadectid form, is well preserved. Its height is 21 cm., its length 26 cm.; the length of the iliac blade is 10.5 cm. The humeri are somewhat imperfect in the "shaft" region. As restored, the measurements are: length, 23.5 cm., proximal width 10.5 cm., distal width 16.2 cm. Radius and ulna are nearly complete. The radius has a length of 13 cm., proximal width 6.7 cm., distal width 7.2 cm.; the ulna has a length of 18.8 cm., width across articular region 7.8 cm., distal width 6.1 cm. Except for the proximal end of one tibia, the major bones of the hind legs are well preserved. Their measurements in centimeters are as follows:

	Femur	Tibia	Fibula
Length	22.9	16.2	18.9
Proximal width	10.4	8.2	6.0
Distal width	11.1	7.7	9.7

These limb measurements exceed by 20 per cent or so those of characteristic Wichita specimens.[8] On the other hand, isolated elements of individuals of still larger size are occasionally found in the Clear Fork.

It seems certain that in the case of *Diadectes*, as of various pelycosaurs studied in detail by the writer and Price, there was a steady increase in size within species phyla during that period of the early Permian covered by the Wichita and early Clear Fork deposits; a type of phyletic "drift" observable in the case of most common types throughout the history of vertebrates. It is unfortunate that the absence of fossil remains in beds

[7] Romer, A. S., and Price, L. I.: 1940, Review of the Pelycosauria. Geol. Soc. Amer., Special Papers No. 28, p. 428.

[8] Cf. for example, the figures given by Case, 1911, p. 88.

higher than those of the lower Clear Fork does not permit us to observe the end results of this trend towards gigantism.

A considerable amount of foot material was found, but unfortunately not articulated, so that identification is difficult. One pair of elements, however, is readily identified and well preserved—the fused astragalo-calcaneum (Text Fig. 3).

In the few previously described examples of diadectid foot remains, astragalus and calcaneum are distinct, as in early reptiles in general. Here, presumably in correlation with the advanced age of the individual, the two elements are almost indistinguishably fused. The condition suggests that in diadectids in general, there was no motion possible between these

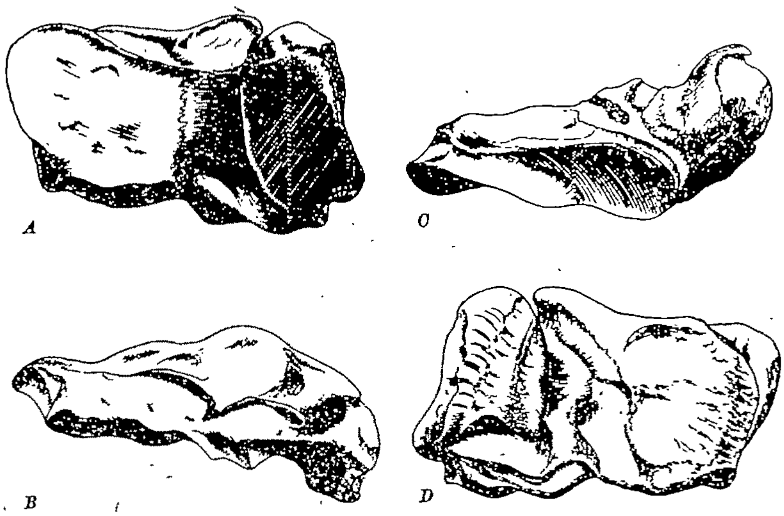


Fig. 3. Right astragalo-calcaneum. A, dorsal; B, distal; C, proximal, and D, ventral aspects. x 2/5.

bones, and it may be that even in cases where two separate ossifications are seen, astragalus and calcaneum were continuous in cartilage. The line of fusion is indicated by rugosities along the region of sutural obliteration, and by the presence of the foramen for a perforating vessel; a foramen represented in typical early reptiles by a pair of apposed notches on the two elements.

The calcanear portion of the bone is a relatively thin plate, with nearly smooth upper and lower surfaces. Proximally there is a broad facet for the lateral portion of the fibula.

The lateral surface is unossified. The distal margin is occupied by an articular surface whose principal contact was presumably with the fourth distal tarsal. A slight projection along the dorsal surface of this margin suggests that the relatively smaller area lateral to this point articulated with a fifth distal element.

The astragalar portion of the bone is much thicker. Proximally it bears an articular face for the fibula, continuous with that above the calcanear portion; this face is turned somewhat dorsally as well as proximally. The lateral margin is covered in great measure by a large oval surface upon which the tibia was supported; this faces somewhat anteriorly and proximally as well as laterally. Ventral to this there is, as usual in early reptiles, a thickened rugose area presumably associated with muscle tendons. The distal surface is occupied by an articular face for more distal tarsal elements, presumably two centralia. The medial portion of this surface is flat, the lateral area, close to the foramen, markedly convex and essentially hemispherical.

Apart from the fusion of the elements, the structure is essentially similar to that of the astragalus and calcaneum of captorhinomorph cotylosaurs.

This tarsal fusion is of possible significance with regard to the relationships of the diadectids. A similar situation is found in certain later reptiles: Rhynchocephalia and many Lacertilia and Chelonia. Among early types it is found, however, only in certain other cotylosaurs: the pareiasaurs and *Telerpeton*, a member of the procolophonid group. The structure seen in pareiasaurs is seemingly similar to that here described in *Diadectes*, although Hartmann-Weinberg[9] believes the large tarsal to include elements other than astragalus and calcaneum. Watson[10] believes that diadectids, pareiasaurs and procolophonids are related groups of cotylosaurs, which he unites as the Diadectomorpha. The tendency toward tarsal fusion now seen to be present in all three types is evidence supporting his conclusion.

[9] Hartmann-Weinberg, A.: 1929, Ueber Carpus und Tarsus der Pareiasauriden. Anat. Anz., LXVII, S. 401-428.

[10] Watson, D. M. S.: 1917, A sketch classification of the Pre-Jurassic tetrapod vertebrates. Proc. Zool. Soc., Lond., 1917, p. 171.

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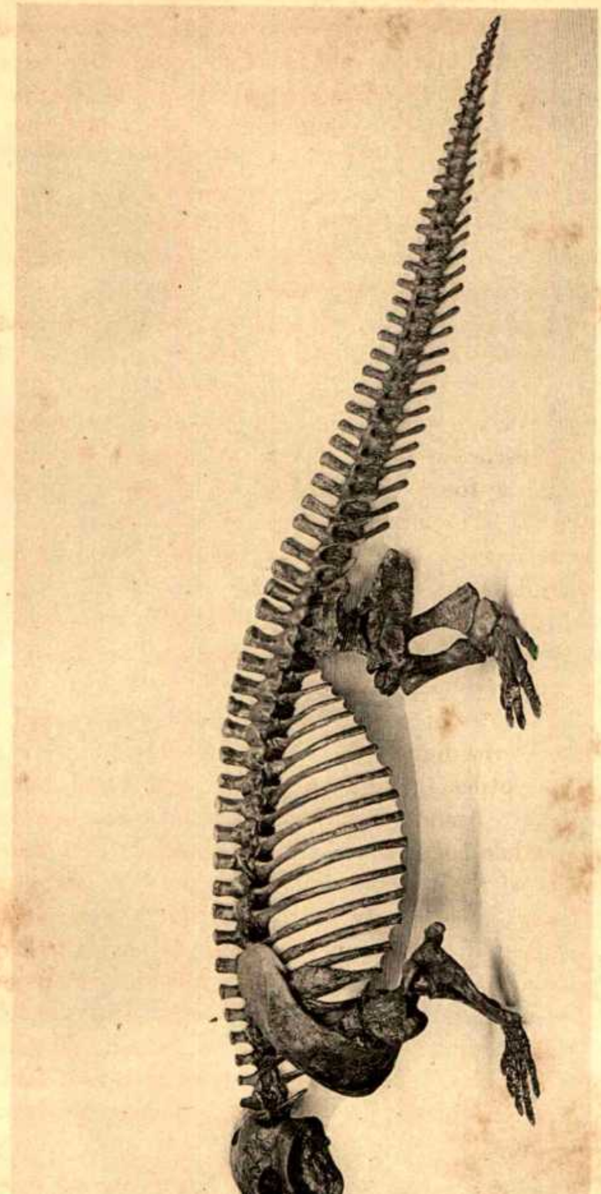

Mounted skeleton of *Diadectes tenuitectus*. Length as mounted, 235 cm.

TERTIARY MAMMALS AND CONTINENTAL DRIFT.

A REJOINDER TO GEORGE G. SIMPSON.

ALEX. L. DU TOIT.

ABSTRACT. Doctor Simpson's criticisms are opportune, pertinent and helpful, although partial, through being confined to the rôle of the mammals, while ignoring the overshadowing geologic and tectonic evidence—Tertiary and older. The Cretaceo-Tertiary Land-bridges of du Toit are the logical outcome of the Earth's structural pattern *whether Drift be admitted or not*, and must therefore be viewed as essentially orogenic in character and generally linear, narrow, impersistent and imperfect, particularly during their later history.

Simpson has merely shown that such inter-continental linkages could not have persisted as long, nor have permitted terrestrial migration as freely, as believed, but he has by no means disproved the probability of Continental Drift, which has been based on a wealth of other evidence, much of it long antedating the evolution of the Mammals.

INTRODUCTION.

CRITICS of Continental Drift are apt to forget that this conception—like the accepted science of Geology—is still being shaped and must experience revisions and modifications during its evolution, more especially in regard to inter-continental linkages during the Tertiary. They are equally liable to ignore the fact that current ideas on such linkages are often unhelpingly vague and too frequently lack a strictly geologic basis.

When hypotheses of Drift are being criticised, it is essential that the particular scheme of former continental spacing and movement be specified, since there is as yet no true consensus of opinion on the subject and several different systems have thus far been advanced. The citations made from Wegener are usually from the English translation of the third German edition of 1922, regardless of the fact that several revisions have appeared thereafter, the latest being the French version, dated 1937, of the fifth and last German edition. (9) In this latter the chapter on Paleontologic and Biologic Arguments embodies much new matter as well as extensive quotations from recent literature, all of which the reader is earnestly invited to study. For that reason this particular aspect will only be dealt with briefly.

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Realising the value to the problem of specialised knowledge, the writer issued in 1937 an invitation to authorities to coöperate, a challenge which has been accepted by Dr. G. G. Simpson, speaking on behalf of Tertiary Vertebrate Paleontology. In a trenchant article in THE AMERICAN JOURNAL OF SCIENCE entitled "Mammals and the Nature of Continents,"[4] he has set out to prove that the evidence of mammalian distribution, while limited in scope and time, is adverse to hypotheses of trans-oceanic or drifting masses, but favorable to current views of stable continents. In contravention it may be questioned whether the mammalia have not created amost more biogeographic difficulties than they have solved. Even Matthew (3; p. 299) is forced to admit a discordance between the vertebrate and invertebrate evidence. Regrettably they have been robbed of much of their value through their late appearance on the scene, well after continental rupturing is deduced to have occurred, yet while such supposed movements were in full swing.

Since Simpson refers at length to the writer's particular views, but has at times failed to present them correctly, or has omitted their other vital aspects, it becomes necessary to go into greater detail than would otherwise have been necessary, so as to clear up important differences of statement or interpretation.

It is true that paleontologists have thus far not shown any leanings towards the new ideas and seemingly remain "orthodox" in outlook, but such is understandable for, as the writer remarked in 1927 (6; p. 118), "geological evidence almost entirely must decide the probability of this hypothesis for those arguments based upon zoö-distribution are incompetent to do so." After studying Simpson's paper and consulting those authorities cited therein that are available in South Africa, the author sees no reason for modifying that apparently sweeping pronouncement. For argument, the finding of identical mammalian species in, say, Madagascar and Rhodesia would merely indicate a former land-connection, but in the absence of other information would not prove whether Madagascar had at the time lain 10 or 1000 miles distant from Africa or had been attached thereto *via* Natal, Mozambique, East Africa or Somaliland. Those common fossils would only say "yes" and "when," but not "where," or not with the precision desired. Furthermore, as contrasted with other methods, paleontologic comparison suffers from cer-

tain disabilities, as set forth below. Within those limitations excellent use can be made of this valuable arm, and in the case of the mammalia, from the Eocene onwards. Perhaps the above may help to explain the remarkable paradox that, while paleontologists as a body are antagonistic towards Drift, the protagonists can claim that their views are actually supported by paleontologic data. For that matter Simpson has done signal service by pointing out serious errors not only in initial identifications or comparisons, but in the perpetuation of those mistakes through lack of critical study of the original sources, in which the writer must incidentally admit to having shared.

Study of the many, varied and conflicting opinions expressed by more than one generation of biogeographers reveals most strikingly the serious difficulties, surprises and dilemmas encountered by them, which collectively leave a strong impression that some elusive, though vital, principle must have been missing from their particular ideas of past continental linking. It is more than significant that, of those welcoming the hypothesis of Drift, so goodly a number have been biologists. One of the exceptions is Matthew (3; pp. 202–9), who practically eliminates land-bridges and is seemingly content to explain faunal relations on the Noah's ark principle, though even so he runs into difficulties. The notion of random, and sometimes two-way, "rafting" across the wide oceans, which he favors, evinces, however, a weakening of the scientific outlook, if not a confession of doubt from the viewpoint of organic evolution.

PALEONTOLOGIC HANDICAPS.

a) *Paleontologic Record.* The "imperfection" of the record is universally deplored. Everywhere, though more particularly in the southern lands, paleontologic knowledge has lagged, and must continue to lag, far behind geologic. Not only are the terrestrial less known than the marine Tertiaries, but they have been, as Matthew points out (3; p. 178), eroded from over wide areas, and the gaps in our knowledge concerning their life must be considerable, whereas the corresponding marine faunas are relatively well known. Conclusions from the meager finds recorded must largely be tentative. Furthermore, unlike present-day life, the scanty vertebrate fossils have in the main been collected from few and widely separated deposits in which the recorded proportions of the determinable genera and species could be very different from their actual frequency in

nature. Such assumes importance when faunal resemblances are tabulated on a percentage basis, as done by Simpson (4; p. 20). The scantiness of such material cannot be overlooked nor the likelihood of unexpected discoveries that would appreciably modify current ideas. Negative evidence must be quite unreliable therefore.

b) *Instability of Determinations.* Although writing without "special competence" in this field, the author has been struck by the fragmentary nature of so much of the material labeled generically or specifically, the periodic changes in nomenclature brought about by subsequent revision, the departures in opinion regarding affinities expressed by men of eminence, etc., so well exemplified by Simpson's account of the history of *Neotragoceros* (4; pp. 24–5). The observer is led to speculate inhowfar the genera and species listed to-day, and of course their affinities, would remain appreciably unaffected by future work and better material. All this is apart from that fundamental question, which cannot be discussed, "What actually constitutes a Species?"

c) *Wrongful ascription.* To the examples quoted by Simpson can be added the incorrect identification of forms because of their association with admittedly related fossils. One example of outstanding importance will be cited, namely the recording by Amalitzky in 1899 of typical members of the Glossopteris Flora together with "Karroo Reptiles" in the Permian of Russia, an association that has never been questioned, at least in print. While the Karroo affinities of the Russian vertebrates are beyond doubt, the writer's examination in 1937 of several of the types identified as *Gangamopteris* and *Glossopteris* by Amalitzky, or of duplicates so labeled by him, showed that those particular specimens, while outwardly very similar, yet failed to agree in their venation with those type genera of the Glossopteris Flora. That Amalitzky should have been so misled is under the circumstances quite excusable, but this instance gives rise to speculation whether other analogous cases of paleontologic inexactitude might not exist unsuspected.

d) *Specific Determination.* In the early days of research specific determinations in far-off lands were, and understandably, made with the well known forms of Europe. With progress and the realisation of faunal provinces, the institution of local species became inevitable, a policy which may perhaps have been overdone. A disturbing psychologic factor, which

is quite distinct from the "personal equation" must here be pointed out: namely the natural tendency to compare new finds with material described from corresponding formations nearest to hand. It is probably difficult to keep this "distance factor" under subjection, since any tendency to make specific comparison with rather similar forms from half way round the globe could so readily be regarded as incautious, with the contingency that the closer relationships of far-separated faunas might for long escape notice. In not a few cases again the more distant faunas, particularly if the relevant literature be in some foreign language, are liable to be overlooked, with the same ultimate result.

With the continents viewed as no longer fixed, this aspect becomes one of actual concern, and indeed, if the feasibility of drift be conceded, ***reconsideration of the long-distance correlation of faunas*** generally would appear to be inevitable. Until a considerable amount has been done in that direction the existing paleontologic evidence can be accepted only with reserve by those favoring drift.

FAUNAL RELATIONSHIPS.

The degree of similarity between any two faunas unquestionably presents great difficulties. Simpson has exposed several weaknesses in the writer's statements and arguments on this subject, some of which are frankly admitted, due primarily to the inherent tendency to stress the points of similarity for the very reason that the areas concerned happen to be so far apart to-day. Such relative accentuation finds a parallel when a paleontologist speaks of "highly fossiliferous Cambrian" when he means "highly fossiliferous for the Cambrian." Simpson criticises the writer's statement "2) faunal differences at the ends of a link, as von Ubisch (quoted by Wegener) has pointed out, ought to be appreciable owing to the differentiation that must have occurred along the bridge itself, whereas a close specific relationship or even identity of forms may indeed characterise the life of the now-opposed lands," in which certain, and not all, forms were so obviously indicated. He then says "If, as the logical alternative, he means to say that identical faunas have been found on separate continents, then he is even farther from the truth," thereby enlarging the idea of certain closely specific or identical forms (*not* faunas) into one of identical faunal assemblages.

With no desire to detract from the true value of paleontologic comparisons, but the weaknesses exposed in the preceding section in mind, a protagonist of drift may be pardoned for feeling some reasonable doubt whether the mathematical comparisons of similar or related species of distantly-spaced faunas, as compiled from current literature by Simpson (4; p. 20), Arldt or others, are as real as he is asked to believe. The instance cited of the apparent lack of identical species among the Triassic reptiles of Brazil and South Africa should not strictly be pressed in view of the limited amount of collecting, the high ratio of new genera and species so far found, and conceivably the "distance factor." Even under the closest fitting of the continents permissible, the distance between the two areas could not have been less than 1800 miles.

Accepting, however, as a basis of discussion Simpson's percentages (4; p. 20) as applied to faunal relationships, they but serve to emphasise the *rapid falling off of specific similarities with distance*, even within the confines of a single landmass, a peculiarity which is quite well marked among the living faunas. With a long and narrow linkage the "con-specific ratio" falls to a surprisingly low figure to become negligible or zero in extreme cases, even when a past union of the particular lands happens to be indicated by other credible evidence. Striking is the lack of common species from among the closely allied Permian reptiles of Russia and South Africa, areas 6500 miles apart.

Now the Cretaceo-Tertiary land-bridges envisaged under Drift (see next section) are essentially linear or arcuate, narrow and unstable, ranging in character, it is thought, from continuous corridors to isthmian links in the sense of Bailey Willis. In not a few instances they would have paralleled Simpson's Case D with a community of families of 67 per cent, of genera 24 per cent and of species 5 per cent, while the respective percentages might well have been lower. In certain instances such bridges would have run with the Earth's climatic zones (Behring Strait; Central Atlantic); in others across them (Malaya-Australia-New Zealand-Antarctica). For post-Eocene times they could in general have corresponded closely with the "sweepstake routes" so aptly defined by Simpson. Even in the case of the Afro-Eurasiatic connections (Spain-Morocco; Egypt-Syria) the limited stratigraphic data are not necessarily in favor of wide bridges across the Mediterranean "Tethys."

Under those circumstances, his contention, that a far higher proportion of common species should be detectable under Drift than is brought out by the recorded fossil mammalia, is greatly weakened. It may be questioned too whether the mammals, by their very mobility and peculiar organisation, could be expected to have migrated with the same presumed uniformity as the ancestors of the living lower orders—snakes, scorpions, earthworms, land and fresh-water mollusks, plants, etc.—which, because of their number and variety are surely of not less importance in this problem, especially as their evidence proves to be not always in accord with that of the vertebrates (3; p. 299). In his latest edition (9; Chap. VI) Wegener effectively quotes authorities such as Michaelsen, von Ubisch, Okland, Huus, Jaschnov, Meyrick, Irmscher, etc., in those other fields.

Despite criticism, the statement "Migration along a link need not be equally effective in both directions" (7; p. 294) is reaffirmed, a cogent illustration being that of Russia and Southern Africa with similar reptiles, amphibians and fresh water mollusks, but different plants during the Permian. Simpson admits (4; p. 17) possible selection during intermigration between continents now separated, though only along limited corridors. Conceivably, with only a very brief spell of linking, something rather like "one-way traffic" could have operated; of such Madagascar would have formed an example. The factors controlling migration must be extremely complex, and, in the case of crustal wrinkles thrust up from the ocean-bed or lavas and scoriae heaped up to above sea-level the laws of biologic spreading within continental areas might not hold good. With fixed continents round-about routes have often had to be postulated by biogeographers—to well within the polar circles sometimes; these, if biologically possible, must have tended towards the elimination of the less adaptable forms, and thus towards selection.

Simpson has had to pass over the abundant non-mammalian life and thus ignore so much of the very evidence that has compelled biogeographers to formulate their individual schemes of past land-connections. Of such living forms admittedly many, probably most of them, have as yet no well known fossil representatives, although of high significance none the less. To argue that such southern disjunctive distribution is due to colonisation from the north through forms not yet discovered in the Holarctic region, is neither scientific nor fair. Attention

can merely be drawn to the remarkable distribution of certain organisms, as done by Wegener and others, not forgetting their parasites (7; p. 294). The plants too have received insufficient attention, seeing that their thermal sensitivity makes them useful through indicating, for example, the difficulties inherent in the assumption that the cold temperate floras of the southern continents, which show unexpected resemblances, must necessarily have been derived from the Holarctic vegetation that flourished north of the climatic barrier set by the wide Tropical Zone. The same argument applies to the fresh-water decapods.

LAND-BRIDGES.

The way of the bridge-builder is strewn with pitfalls. Simpson deplores that, opponent as the writer is of the numerous land-connections of current conception, he (du Toit) has nevertheless accepted several bridges differing from the latter, so it is stated, in no respects, and faulty too in that they could only be broken once, whereas paleontologic evidence would suggest a repeated "make and break."

That is very far from being the case, since under the hypothesis proposed by the writer such connections—save possibly in the extreme northern Atlantic—are viewed as having been essentially of an *orogenic kind*, developed within restricted zones of lateral compression, produced by one crustal block impinging on a second, or else thrown up from an epicontinental sea or even from an ocean by marginal or advance folding in front of a drifting block or blocks. Longitudinal tension and/or erosion, or sinking in the post-orogenic period, would have served to reduce and even to sever such connections. The geologic record is punctuated by such far-extended squeezings (7; p. 48), the Tertiary being in fact marked out by at least three world-wide compressive phases and interludes.

This "segmental oscillation," which Simpson cannot accept, is written large, though in other characters, in the Tertiary fold-girdles, which should dispose of his complaint that under Drift the "make and break," so rightly stressed by him, could not have been cyclic. Is such not perhaps Joleaud's idea of the "accordion movement" under a different guise?

More important still is the fact that such "fold-" or "drift-linkages" have not been flung out at haphazard, but at spots and times closely fixed by the visible and dated crumplings of the crust, and have not been conjured up, as Simpson would

hint, to explain actual or supposed resemblances of the terrestrial life of the continents in question. Indeed the situations of such "bridge-heads" are regarded as *pre-determined,* their prolongations across the lands being in most cases actual major fold-ranges. Even under current views such fold-zones are regarded by a large body of geologists as persisting beneath the present oceans and as having at times in the past projected as island-chains along certain stretches thereof. Accepting Drift, they are merely shorter to start with. It can be asked, and rightly, why, if such be the case, there should be any recourse to Drift. The bitter fact is that current Geology, sublimely unconscious of its impotence, is wholly unable with the continents remaining fixed to account for the tectonics of those fold-zones in a physical, logical and convincing fashion! For an adequate explanation some drift would have to be invoked.

Of no less importance through ruling out any bridge-head is the presence along a coast-line of fringes of purely marine strata—or even their probable former presence, if adequately supported by other lines of evidence. As an example, the little-disturbed Lower Cretaceous to late Tertiary marines bordering the Southern Atlantic exclude from consideration lengthy stretches of African and American shores. On the contrary widespread unconformities or thick non-marine intercalations point to uplift and to possible temporary connections. Paleogeographers have all too frequently overlooked such basic restrictions when locating their bridges.

By the writer the Hypothesis of Drift is regarded as essentially established by the Paleozoic and early Mesozoic evidence; the rest is largely a logical corollary, which in the main is consistent in outline, but has not yet been worked out in detail, for that would be a mighty task. The continents are pictured as having proceeded to "part" during the later Mesozoic as shallow gulfs were extended into and between them under the initial crustal stretching, but actual rupture of the sial shell did not generally take place until the close of the Cretaceous, to pass through a series of climaxes during the Tertiary. Such should dispose of the erroneous idea that at the beginning of the Tertiary the continents were still usually in contact along their edges—making allowance for the widths of the continental shelves—with opportunity for free biological migration.

The true rôle of the mammalia will be the fixing of land-

bridges not in the horizontal, but in the vertical plane, through revealing the uprisings and downwarpings of the crests of such linkages, themselves positioned by other, and mainly older, criteria.

THE NORTHERN CONTINENTS.

That those lands, including Africa and India, had some inter-migration during the Tertiary is proved by the mammalian evidence marshalled by Simpson and needs no stressing. His arguments (4; pp. 8–10) in favor of a connection across Behring Strait are indisputable, while his recognition of its apparently cyclic nature is in agreement with the known triple folding that crosses from Siberia to Alaska, and is not in conflict therefore with the scheme of linking advocated by the writer (7; pp. 186, 298).

On the most vital part of the problem, namely the connection between North America and Europe, Simpson firmly opposes all bridges across the Central Atlantic but concedes some linking farther north, possibly of late date (4; p. 6). Now the bridging of this ocean, with a span of between 900 and 1500 miles across its narrower part, much of it over 1000 fathoms deep, while perhaps a simple matter for the biologist, is a far tougher proposition for the geophysicist, who cannot so readily admit the sinking of non-tectonic crustal blocks of that width in defiance of isostatic principles. Only a narrow linkage of either tectonic or volcanic origin can accordingly be visualised. Outside the presumably local wrinklings of southern England and western Spitzbergen no relics of Tertiary fold-ranges are represented along the North Atlantic, while the Tertiary faulting, e.g. Greenland and the British Isles, although common, is nowhere to our knowledge of truly large vertical displacement. Under current views the only assumption remaining would seem to be a volcanic chain extending say from the British Isles *via* the Faroes and Iceland to Greenland and Canada.

Under Drift the North Atlantic is regarded as having been widened by intermittent tension, a movement least and slowest in the north, with magma erupting from fissures produced in the stretching ocean floor, and building up piles of volcanic material that were in turn ruptured towards the close of drifting, a process that may still be in progress. The problem is admittedly more or less equally explicable under theories of stable or moving continents, but the latter has the merit of forming the logical consequence of a particular scheme of

Earth structure which seems to hold good for the pre-Tertiary eras. The practical outcome, however, is that, when current views are applied to the Northern Continents, the assumptions required are not any simpler, or more probable from the geophysical standpoint.

AMERICAN-EURAFRICAN LINKAGES.

Simpson's exposure of the flimsy nature of Joleaud's paleontologic evidence for Tertiary Central Atlantic connections is welcome, and the writer candidly admits his lapse through citing Gregory in this matter. All the same, the feasibility of double linkages, of an orogenic type, between Central America, Cuba and Spain and Venezuela and Morocco respectively during the Cretaceo-Tertiary, happens to be a consequence of the scheme of drift proposed and is furthermore *independent of any paleontologic similarities between those four opposed continents.*

Those bridges are regarded as having been pressed up under the rhythmic approach of the North American-Eurasiatic and the South American-African masses, but lowered by lengthwise tension under the westerly drift of the Americas as the meridional "rift" of the Atlantic widened. Their persistence above sea-level must have depended essentially on the relative intensities both in space and time of the periodic but contrasted north-south compressions and east-west tensions. The shallow-water marine faunas of those latitudes show that for the earlier Tertiary the state amounting to a line of submarine ridges was undoubtedly attained, while certain resemblances in the terrestrial life, referred to below, suggest that the state of island-chains, or even of isthmuses, was reached. The feasibility of effective transoceanic connections after the Miocene was, however, doubted by the author (7; p. 204) and he should therefore have ruled out as a possible migrant so much younger a genus as *Hipparion*. South Africa has nevertheless yielded Hipparion-like teeth, though their specific characters would appear not incompatible with a northern derivation. While the affinities of the mid-Tertiary fauna of South-west Africa are according to Stromer with North and Central Africa, the specialized hyracoid *Protypotheroides* is allied to the Miocene *Protypotherium* of Patagonia.

Conceding these two structural "fronts"—Central America-Spain and Venezuela-Morocco—approaching each other while being stretched unequally at their western ends, accompanied

by their attendant advance and diagonal folds, the migrational paradoxes of the Central Atlantic that have been forced upon biologists, and that Simpson has found (4; p. 25) so hard to credit, become easier to understand. Indeed, with such long, sinuous, warping and disrupting chains quite unexpected interchanges of terrestrial life could hardly have failed to take place, as remarked by H. B. Baker. As illustration, ignoring Drift, taking a chart of the Caribbean region and delineating simple rises or falls of sea-level, peculiar sunderings or linkings of the various islands would follow, to become more surprising still were even a little crustal warping to be introduced into the process. One should not overlook too the tremendous part played by volcanicity in the building up of the Tertiary ranges, so finely displayed for example in the island-chains of the West and East Indies. Cross-connections or short-circuits might thus be established, as in the case of the Lesser Antilles.

Even with the continents fixed geologic evidence is against any direct connection between North and South America from the Mesozoic down to the late Miocene. How then were the marsupials of South America derived from a pre-Tertiary stock in Europe? The South American monkeys too in their brain development are surprisingly similar to those of the Old World. Each truly demands an early Tertiary trans-Atlantic bridge! While Simpson has been so far successful in disproving any free intermigration of the mammalia across the mid-Atlantic during the latter half of the Tertiary, there remains in favor of an earlier bridge or bridges, as well claimed by numerous biogeographers, quite a number of lower animals and plants, the distribution of which forms a stubborn problem under views of fixed continents.

AUSTRALIA-ANTARCTICA-SOUTH AMERICA.

While Simpson severely questions the mechanics advocated by the writer in regard to these continents, a study of du Toit's restoration (7; Fig. 7) and of an artificial globe will show that the maximum displacement of Australia would not have been much more than 2000 miles. Even assuming his extreme proposition, that all such movement had been concentrated into the post-Oligocene period, Australia in order to reach its present position would only have had to "speed" at under six inches per annum. There is also the alternative that, although the parent mass had been broken into its three parts at an earlier

date, intermittent contacts could still have been maintained between those portions by the circum-Pacific Tertiary fold-zone running through Patagonia, Grahamland, West Antarctica, New Zealand, New Guinea and the East Indies, which last is a global fact and quite independent of any special theory of Earth structure. The existence of such a lengthy ridge finds support from the great resemblances of the Miocene marine littoral faunas of Patagonia, Australia and New Zealand, as stressed by van Ihering, Ortmann and Hedley.

The curving of that fold-zone around Australia shows how that block, twisting anti-clockwise, attempted to by-pass Indo-Malaya, thereby permitting the Asiatic wave-front to press out into the Indian Ocean with the development of crustal swirls, while the Australian wave-front escaped into the Pacific. Conditions tending towards the production and destruction of linkages between Asia and Australia were accordingly to hand. Umbgrove (8; p. 34) has recorded the surprising shallowness of the seas over the vast East Indies region throughout the Tertiary—in strong contrast to the Mesozoic—with intense folding during the mid-Miocene, large parts having certainly been land in the Eocene and Pliocene. The intensity and rapidity of the Pleistocene movements, that led to the upheaval of coral reef-terraces for many hundreds of feet, to the tearing out of astonishingly deep oceanic basins, etc., have been fully set forth by the Dutch geologists, although little known generally. Under the universal lowering of sea-level in the Pleistocene New Guinea, Australia and much of the East Indies —"Sundaland"—must for a time have become joined by low-lying ground.

As against all this evidence paleontologists and biologists alike have tended to stress the biologic isolation of Australia from the early until the very late Tertiary, a relationship which must surely have been less likely with the continents fixed than with Australia far away and only drifting towards Asia. In regard to the marsupials—and in such the writer stands corrected—Simpson denies any special resemblance between those of South America and Australia, though he does not appear to be so happy about the family Dasyuridae or Thylacinidae of the order Polyprotodontia and the one advanced order Diprotodontia[1], possessed by both continents. Sug-

[1] The sole South American genus *Caenolestes* could admittedly be an aberrant polyprotodont, as believed by Broom and Diderer.

gestively their respective parasites are identical according to Breslau (9; p. 105). He reluctantly admits that, giving that evidence its maximum weight, any southern connection could only be "something of the order of discontinuous evanescent island chains." One is tempted to speculate whether any part is played by the "distance factor."

The contrasted, yet homologous relations of South America and North America on the one hand and of Australia and Asia on the other can advantageously be considered together. Marsupials appeared in the Mesozoic in North America and Europe, but neither they nor their Tertiary descendants seem as yet to be known from Asia or Africa despite the fact that all those lands were interconnected during the early Tertiary. Now according to Simpson they could not have reached South America or Australia from the north, since those continents were under his, as well as under current, views then unconnected with the northern lands. Had such been the case those southern continents should logically have received other northern vertebrates. Strikingly, early Tertiary marsupials have not yet been recorded from Asia or Australia though their future discovery there is not denied. For the present, until the paleontologist can explain away such paradoxes, he can scarcely maintain that the balance of existing knowledge negatives any Tertiary connection between South America and Australia—from both of which Southern Africa had already become detached.

Admittedly in those two continents the resemblance among the marsupials only extends to families and those lands are not therefore con-specific, while the monotremes are absent from South America and the edentates from Australia. Accepting Drift, however, Australia could never have been closer to South America than 3000 miles—as measured across Antarctica—from either side of which central mass those continents ultimately broke away. Any very close faunal resemblances between those far-sundered and isolated lands could well be lacking, an explanation anticipated by Wegener (9; p. 106).

The significance of other terrestrial life should on the other hand not be overlooked, such as the presence of giant birds, fossil or living in the "Gondwanaland" region—in Patagonia, Seymour Island, Antarctica, South Africa, Madagascar, Australia and New Zealand—while the distribution of the freshwater fishes is highly suggestive (Eigenmann). Striking are

the fresh-water crayfishes of South America, Australia, New Zealand and Madagascar—but not found in Africa—separated as they are by the equatorial zone from those of the northern hemisphere (Ortmann). Matthew's explanations are far from satisfying. The scorpion family Bothriuridae is restricted to South America and Australia (Hewitt). Those curious worms, the Phreodrilidae, are confined to the colder parts of the South Temperate Zone, including Kerguelen and the Falkland Islands. The botanical affinities are much more marked between South America and Australia than between either of them and Africa (Hooker, Hemsley, Bentham and Andrews).

In the face of the above faunal relationships, which could be greatly extended, there would seem to be a *prima facie* case for a former linking or linkings between South America and Australia *via* Antarctica during the Cretaceo-Tertiary, an opinion stoutly maintained by not a few eminent biologists and geologists.

MADAGASCAR.

In regard to the separation of this island from Africa the mechanics are not so puzzling as Simpson would suggest (4; pp. 27–9). Whether Drift be accepted or not, the controlling factor was clearly the lengthy geosyncline, developed in the Paleozoic, that ran down the eastern margin of Africa and covered the western half of Madagascar. Various geologists have contributed towards the elucidation of its history. The formations along both sides of the Mozambique Channel dip towards the latter and indicate through their dominantly marine and occasionally terrestrial phases the deepenings and shallowings of that trough from the Lower Permian onwards, with intermittent but progressive lengthening, until in the late Cretaceous it penetrated to the South Atlantic (see 7; Figs. 11 & 12).

The affinities of the later Cretaceous marine faunas in this region show that, while this trough was in existence, peninsular India must have been prolonged southwards to Madagascar to form a joint barrier such that mollusks from the Mediterranean and North-west India were able to enter western Madagascar only in limited numbers but failed to reach round to the Madras area and beyond, where a different fauna held sway. Marine older Tertiaries fringe western Madagascar dipping towards the Channel, and the island must then have

been cut off from Africa, but stratigraphic gaps at the Oligocene and about the Miocene show that, through slight shallowing of the geosyncline at those times, Madagascar could again have become linked to the mainland. Its geologic history during the Pliocene is unknown, though during the Pleistocene the sea-level fluctuated more than once. Simpson's statement (4: p. 27) that "it contains early Tertiary groups without their later Tertiary relatives abundant on adjacent continents, mid-Tertiary groups with neither their early nor their late Tertiary allies, and late Tertiary to Recent groups such as are always, elsewhere, accompanied by members of other groups [are] here quite lacking," is quite consistent with the stratigraphic evidence.

From the data available the writer has deduced the intermittent stretching of the crust during the Jurassic and Cretaceous with slow widening of the geosyncline (7; Fig. 12) and the outpouring of lavas, its actual rupture in the Eocene, the gradual drifting of the Madagascar block to the south—in the wake of Antarctica—with tilting to the west-north-west along with vast extrusions of lavas in East and Northeast Africa and the Deccan as Australia and India drew away from Africa. In the case of Pemba Island its separation from the mainland is set by Stockley (5; p. 239) as late Miocene or early Pliocene. Any closer dating of those separations would have to be furnished by the terrestrial fossils, and among them the mammalia, though the evidence provided is not only limited but confusing. From its home opposite Kenya and Tanganyika—duly fixed by abundant and consistent data—Madagascar would have had to travel about 600 miles, though in a direction largely parallel to the mainland, a point of high importance when possible re-connections with the latter are in question.

An Upper Cretaceous connection between South America, Madagascar and India is suggested by the dinosauria (von Huene; Matley), though Simpson does not explain how that evidence can have been misinterpreted. Even allowing for isolation and lack of knowledge concerning its fossil representatives, the living Malagasy fauna remains as much a puzzle as ever. Matthew (3; p. 203) views the insectivore Centetidae as the earliest colonisation, perhaps pre-Tertiary, and the lemurs, rodents and viverrines as about mid-Tertiary. On the basis of the more primitive types of lemurs Gregory (1; p. 372)

regarded Madagascar as isolated from India by the Oligocene, before India had been occupied by the more advanced lemurs. After the beginning of the Tertiary the contacts with Africa were manifestly slight and any linking must have been, as suggested earlier, brief.[2]

H. F. Standing has shown that among the lemurs of Madagascar there are closer analogies with the monkeys of South America than with those of the Old World, which brings out the fact that there are positive resemblances with South America, as long pointed out by Wallace, Lydekker, Gregory and many others, which are explicable under the particular scheme of linking discussed earlier. To mention only a few cases there are the boas, iguanas and certain of the earthworms (Acanthodrilidae) which suggestively are unknown north of the equator.

Matthew (3; pp. 203, 206–7), whom Simpson follows with approval (4; pp. 28–9), explains such peculiar relationships as due to occasional introductions from Africa by "rafting," an hypothesis which in view of the limited distances involved—400 miles across the narrowest part of the present channel—is quite conceivable. If true, there was apparently no return rafting, while the African monkeys obviously failed to make the journey. The fact, however, that analysis of the Malagasy fauna shows it to embrace diverse elements, which, as Simpson himself points out, would seem to mark out distinct phases of the Tertiary, while those in turn can be correlated with deduced crustal movements in that region, all forces one to associate such elements with terrestrial linking rather than chance rafting. One can even doubt the alleged natatory abilities of the Malagasy hippopotami (Lemoine) or the dinosaurs (Matthew). The flora of Madagascar does not provide much help, being strictly endemic and much diversified, but demands a closer study from botanists.

To sum up, the faunal relationships between Madagascar and Africa prove not less puzzling with fixed than with moving

[2] The writer's reference to Gregory queried by Simpson (4; p. 28 footnote) comes from (1; pp. 812 and 872) and applies to the Afro-Malagasy mass; that ascribed to Lydekker (2; p. 1009) arose from his cryptic remark that the Malagasy fauna "is much more distinct from the Ethiopian fauna than is the latter from the fauna of either the Oriental or the Holarctic region."

continents, though explicable by the latter hypothesis under the reasonable assumption of very brief post-Cretaceous connections. Those with South America and Australia are difficult to interpret with stable continents since in several critical cases either the ocean or the equatorial zone would have prevented migration from the Holarctic region. On the contrary the relationships would follow logically from Drift.

CONCLUSIONS.

Doctor Simpson's positive assertion, that "the known past and present distribution of land mammals cannot be explained by the hypothesis of drifting continents," can be met with a not less emphatic contradiction.

Anyone who sponsors a new hypothesis must unhesitatingly investigate every conflict with facts and modify his views accordingly, and Simpson's contribution—long overdue—is therefore valuable through clearing away sundry errors and misapprehensions, reviewing faunal relations from a new angle and throwing fresh light on a complex and fascinating subject. At the same time he does not seem to have appreciated the multitudinous and weighty geologic evidence upon which had been based the writer's synthesis and in which several of the inherent difficulties had been anticipated. Throughout his paper too he has entirely ignored the vital stratigraphic and tectonic aspects.

What he has really succeeded in proving is that du Toit's Tertiary Orogenic Linkages could not have persisted above the level of the widening oceans down to so late a period as assumed, or that they could not have been continuous enough to permit migration with the freedom hitherto supposed. This consequence, which is fully accepted, clarifies the position and marks a real advance in Tertiary paleogeography.

On the contrary he has not thereby disproved the Hypothesis of Drift, which is regarded as resting upon a far wider basis—one rooted in Paleozoic times at least—while, paradoxically, most of his statements of facts prove, when analysed, far from incompatible with the idea of moving continents, and in particular with the writer's scheme, modified slightly to meet such objections. It is re-iterated that, only under Drift can unstable, though ordered, land-bridges be made available at about the particular places and times required for the intermigration of terrestrial life—linkages which in addition give

the *minimum number of possible routes* and which automatically exclude from consideration a host of other connections that have been postulated, largely on paleontologic or biologic grounds, though without full recognition of possible conflicting geologic or other evidence.

The acid test of that Hypothesis will, it is felt, depend among other things on its ability simply and logically to account for the harvest of fossil forms yet to be unearthed. In the meantime fresh evidence of every kind and new ideas will be as welcome as ever in our attempt to establish on a firmer basis this great revolutionary and far-reaching theory of Earth Evolution, which we owe to the genius of Taylor and Wegener.

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OBITUARY.

RUSSELL HENRY CHITTENDEN

Prof. Russell Henry Chittenden, former Director of the Sheffield Scientific School in Yale University, died December 26, 1943, in his eighty-eighth year.

He was born in New Haven, Conn., on February 18, 1856, the son of Horace Horatio and Emily Eliza Doane Chittenden. The family traced its line back to a William Chittenden who emigrated to this country from Cranbrook, Kent, England, in 1639. The boy Russell received his early education in the public schools of New Haven; his preparation for Yale was obtained in the French Private School also located in New Haven. His earliest interests were in the classics and in teaching but this changed to an interest in science with the result that he matriculated in the Sheffield Scientific School and at the age of nineteen years received his B.S. degree, having offered a thesis entitled "Glycogen and Glycocoll in the Muscular Tissue of Pecten irradians." The thesis was published in 1875 in the *American Journal of Science and Arts* (now the AMERICAN JOURNAL OF SCIENCE) "and at the suggestion of Prof. S. W. Johnson it was translated into German, with his help, and sent to Liebig's *Annalen der Chemie*, where it was eventually published." Its publication in German was destined to play an important rôle in securing Chittenden's admission as a student to Kühne's Laboratory at the University of Heidelberg in 1878. The young man had made his plans to spend a year in Hoppe-Seyler's Institute of Physiological Chemistry at Strassburg and all of his letters of introduction and credentials had been addressed to that University. "On reaching Strassburg, however, and presenting the letters of introduction, and after viewing the facilities provided in the laboratories, there arose a grave suspicion that perhaps Strassburg after all was not best adapted for his needs." He was disappointed in both the city and the laboratory. He therefore went on to Heidelberg and presented his card to Professor Kühne. Upon reading the name Kühne asked "Are you the Chittenden who published in Liebig's *Annalen* a year or so ago an article on glycogen and glycocoll?" He was welcomed to Heidelberg, and thus began more than twenty years of close friendly relations with Kühne who died in 1900.

It is of interest to know that the first laboratory for the teaching of physiological chemistry was established in the Sheffield Scientific School in 1874, and over this laboratory Chittenden was placed in charge while still an undergraduate student. The B.S. degree was obtained in 1875. The year spent in Europe (1878-79) served as a great stimulus. Chittenden returned imbued with the idea of making his laboratory a place where physiological chemistry should

be cultivated as a broad biological course of study instead of something restricted to a branch of applied science such as medicine, for example. In 1880 he received his Doctor of Philosophy degree from Yale. He was appointed Professor of Physiological Chemistry in 1882 and held this post for forty years, when he retired as professor emeritus. In 1898 he became Director of Sheffield Scientific School and served in this capacity until his retirement in 1922.

The first phase of Chittenden's research career after receiving his professorship was characterized by interest in problems of digestion. This was no doubt the result of his experience with Kühne who is remembered as the man who gave us the word *enzyme* (in yeast) as the name for specific agents that are responsible for digestive changes. Between 1875 and 1888 forty-six research papers were published by the Laboratory. Some of these were published jointly with Kühne. Approximately half of the papers dealt with some phase of the chemistry of digestion and its products. Chittenden's productivity as an investigator was soon recognized by his election to membership in the National Academy of Sciences in 1890. In 1898 he was President of the American Society of Naturalists

It is not generally known that he was one of the "leading lights" in the early days of the American Physiological Society and did much to promote the use of chemical methods for the study of problems in physiology. The Society was founded in 1888. In 1891 Chittenden was elected a Councilor and served in this capacity for five years. In 1896 he was elected President and reelected eight times. His immediate predecessor as President in 1895 was H. P. Bowditch; his successor in 1905 was W. H. Howell.

The American Society of Biological Chemists was organized in 1907 and Chittenden was its first President. As the virtual founder of physiological chemistry in this country it no doubt seemed natural to elect him President of the first professional society to be established in this field. In 1904 Chittenden was made a member of the American Philosophical Society. Other societies that claimed him as a member in later years are the American Academy of Arts and Sciences, the Societe des Sciences Medicales et Naturelles de Bruxelles, and the Societe de Biologie in Paris.

Chittenden assumed the directorship of the Sheffield Scientific School in 1898. For some time he continued to lecture to classes but after 1908, when Lafayette B. Mendel was appointed to a professorship, the active direction of the laboratory was in the hands of Mendel. As might be expected, administrative duties took more and more of Chittenden's time, and his ambitions for the development of science took the form of promotion of the interests of Sheffield Scientific School. During this second phase of his career, however, he became greatly interested in the problem of the amount

of protein required for health by man, his interests being fanned by his experience in the fall of 1902 and early part of 1903 with Mr. Horace Fletcher, the man who advocated extensive chewing of food before swallowing as a means of obtaining the maximum of nourishment from it. Chittenden saw certain problems in this connection that were amenable to attack in the laboratory and therefore organized such an attack. Nitrogen equilibrium studies were conducted on himself and four staff colleagues, eight college students and thirteen soldiers who volunteered for this work. These studies led to the conclusion that the normal adult can be maintained in satisfactory nitrogen equilibrium on a daily intake of protein less than one-half that required according to the Voit standard then current. These experiments were described in a book entitled "Physiological Economy in Nutrition" published in 1905. The studies were extended to include observations on dogs, and then reviewed in lectures delivered before the Lowell Institute in Boston in 1907, which were published in another volume entitled "The Nutrition of Man." These books appeared just a few years before Osborne and Mendel made their classic discovery that proteins differ in their biological value and this difference is related to the amounts of the respective essential amino acids present in the protein molecule. These later developments were of course very important and served to direct the study of the rôle of protein into new channels. It is true, nevertheless, that the most recent statement of a standard of daily protein intake for man, that put out by the Food and Nutrition Board of the National Research Council in 1941, suggests a figure slightly higher than that advocated by Chittenden. It would seem, then, that a compromise figure has been arrived at after all these years.

During the administration of President Theodore Roosevelt Dr. Harvey Wiley began his "pure food" crusade and fought the use of chemical preservatives in foods. Along with many other substances that might be mentioned sodium benzoate was considered by Wiley to be toxic. As a result of the controversy thus engendered President Roosevelt appointed the famous Remsen Board to study and report on the toxicity of sodium benzoate. Doctor Chittenden was a member of the Board, and in this capacity carried out experiments on the problem. The report of the Board was essentially negative.

Other important public services by Chittenden were rendered during World War I when he was appointed a member of the executive committee of the National Research Council. After the War he visited London, Paris and Rome as representative of the United States on the Inter-Allied Scientific Food Commission.

It is not generally appreciated how much Chittenden did to stimulate bright young men to enter medicine and its related sciences.

Many of his students became very distinguished in medicine. It was largely this fact that led the Connecticut State Medical Society in 1984 to exercise its unusual charter prerogative to confer degrees and thus to give him in his seventy-eighth year an Honorary Doctor of Medicine degree. What his reaction to this honor was it is difficult to say since it came so late in life after he had already received honorary degrees from the University of Toronto, University of Birmingham, England, Washington University, and the University of Pennsylvania. In this case, however, it was a most unusual testimony to the influence he had exerted as a teacher in his younger days in directing toward medicine so many of the young men who listened to his stimulating lectures and had pictured to them the great possibilities that the new science of physiological chemistry afforded to medical science.

It was Chittenden's good fortune to live to a "ripe old age" and thus to see his chosen science developed through two generations of students besides his own. This was doubtless the chief reason why he was asked to write for the American Chemical Society the monograph entitled "The Development of Physiological Chemistry in the United States." Since his was the first laboratory in this field to be established in this country, there is some truth in the statement that "with his passing an era in physiological chemistry came to a close."

GEORGE R. COWGILL.

SCIENTIFIC INTELLIGENCE

PHYSICS.

Electronic Physics; by L. C. HECTOR, H. S. LEIN, and C. E. SCOUTEN. Pp. viii, 355; 289 figs. Philadelphia, 1943. (The Blakiston Co., $3.75).—This is an elementary text for the beginner in the realm of electronic physics, from its inception in frictional electricity as known to the Greeks to the cyclotron and artificial transmutation of elements. On the assumption that the modern beginner in the field of electricity prefers a modern explanation, the historical background has been kept to a minimum and the subject is treated from the electron-proton point of view.

Although most books on this subject do not treat light, this book has included five chapters on the nature of light and the elementary theory of lenses, mirrors, and prisms. Light is thus integrated with its allied subjects in the electromagnetic spectrum, X-rays, wireless, and the infra-red and ultra-violet. In this connection photoelectricity and the vacuum tube are covered briefly.

Each chapter is headed by a paragraph setting forth the general principle to be covered in the chapter, and its general method of procedure. It concludes with a list of the important facts presented in the chapter and three groups of problems. The first two groups are graded problems which require simple explanations or numerical work for which the answers are given; the third group suggests elementary experimental problems. An added aid to the student is the use of red in the line diagrams to point out the important elements.

Using simple language and simple presentation with a minimum of mathematics, the authors seem to have attained their goal of producing a modern text for beginners in the field of electronics.

JAMES O. BUCHANAN.

Physical Sciences; edited by WILLIAM F. EHRET. Pp. 689. New York, 1942 (The Macmillan Co., $3.90).—The material presented in this book covers the fundamentals of the physical sciences: mathematics, astronomy, physics, chemistry, and geology. The emphasis throughout is on the scientific method and its applicability to all forms of science. Each science is presented not only as holding an individual position in man's knowledge of the universe, but also as being dependent on the others.

The greater part of the text is devoted to physics, chemistry, and geology. While mathematics is used freely as a tool for each, no advanced knowledge of mathematics is needed since use of calculus has been avoided. This renders the book suitable as a text for a general survey course in the physical sciences at the college level. The material is well integrated, one subject following out of ideas

previously set forth. For example, geological phenomena are shown to be the results of chemical and physical action. In all cases the problems are kept general, and it is the principles of the subject and the scientific approach to them that receive the emphasis.

As an incentive to the more interested student, suggested topics for further study and parallel references have been included at the ends of the chapters. Throughout the book the authors have endeavored to keep to a rigorous approach, the practical and historical treatments being of secondary importance to them. The background gained from a book of this type is a more thorough understanding of present scientific knowledge and of the methods of obtaining this knowledge. JAMES O. BUCHANAN.

CHEMISTRY.

Proteins, Amino Acids and Peptides as Ions and Dipolar Ions; by EDWIN J. COHN and JOHN T. EDSALL, including chapters by JOHN G. KIRKWOOD, HANS MUELLER, J. L. ONCLEY and GEORGE SCATCHARD. American Chemical Society Monograph Series, No. 90. 686 pages. New York, 1943 (Reinhold Publishing Corp., $13.50).—The interionic attraction theory of Debye and Hückel and the discovery of Bjerrum that aliphatic amino acids are charged both positively and negatively have given for the first time a valid basis for the interpretation of the properties of these substances and an approach to a reasonable theory of the more complicated peptides and proteins. This treatise contains a comprehensive account of these important compounds from this point of view.

Following the general introduction (Chapter 1), the Raman spectrographic evidence for the presence of dipolar ions in amino-acids is presented (Chapter 2). This is followed by a well constructed and brief general introduction (Chapter 3) to the thermodynamic theory of ionic solutions and the interpretation of thermodynamic properties in terms of the Debye and Hückel interionic attraction theory by Professor Scatchard. The theory of the properties of solutions of dipolar ions is reserved for Chapter (12) where a thorough development of the Scatchard-Kirkwood theory is presented by Professor Kirkwood. Chapters (4) to (11), written by Professors Cohn and Edsall, give an exhaustive discussion of the physico-chemical properties of amino acids. Such topics as ionization constants, relations between acidity and chemical structure, dipole moments, apparent molal volumes, compressibilities, heat capacities and surface tensions of dipolar ions are discussed. Interactions between organic solvents and dipolar ions, between two amino acids, and between ions and amino acids derived from solubility and electromotive force data are exhaustively considered.

This fundamental physical chemistry forms the background for the discussion of the properties of the proteins contained in the

second part of the treatise. Chapters (13) and (14) contain the evidence for basic structure of the protein molecule derived from analysis, action of proteolytic enzymes and X-ray diffraction data. Chapter (15) contains an excellent condensed summary of the chemical composition of the proteins. Chapters (16) to (25) contain detailed discussions of the physical properties: densities, molecular weights, osmotic pressures, diffusion coefficients, diffusion and sedimentation in centrifugal fields, acidic and basic properties, rotary Brownian movement, electric moments and solubilities. This part of the treatise is written for the most part by Professors Cohn and Edsall. The exceptions are Chapter (22) on electric moments written by J. L. Oncley and Chapter (25) on the theory of electrophoretic migration by Hans Mueller.

The general character of this treatise measures up to the reputation of the men who have written it. It is logically constructed and well written. But perhaps the most valuable feature is the wealth of factual knowledge contained in this single volume. This condensation of experimental data has been achieved by the frequent use of large tables in the text and appendix. These tables are masterpieces of construction and typographical composition.

There is no doubt that this admirable work will be the standard in this field for many years. Professors Cohn and Edsall should be congratulated on the outcome of their labors and upon their selection of the co-authors. HERBERT S. HARNED.

Cellulose and Cellulose Derivatives; edited by E. OTT. Pp. xix, 1176; profusely illustrated. New York, 1943. (Interscience Pub., $15.00).—Emil Ott deserves high praise for organizing a staff of 35 research workers to present the manifold aspect of cellulose, its natural associates: hemicelluloses and lignin, the methods of its preparation from the natural sources, and its chemical derivatives. "About four-fifths of the material presented in this book has been contributed by persons engaged in industry or working in institutions supported by industry or in government laboratories. . . . The contributions of the academic authors are especially valuable because of their fundamental nature, and will be of great utility to those in industry." (From the "Preface.") Thoroughness has been sought, and achieved, not so much in once more digesting everything that has been published but by describing the practically important properties. From a broad fundament of physico-chemical measurements and calculations, the technical values and applications are discussed with many original contributions of facts and thoughts.

Occurrence (chapter 1) and chemical nature of cellulose (chapter 2) including structure and properties of cellulose in the form of fibers (3) precede the three chapters on the accompanying carbohydrates, lignin and the preparation of cellulose from its natural sources. These, and the following discussion of bleaching and puri-

fication, are relatively short; more space has been allotted to the derivatives and the physical properties (chapters 8 and 9). The technical applications are summarized in the last chapter. Author and subject index are very carefully prepared.

Not only physical and organic chemists, but also paper makers and workers in the field of plastics should find this book of great value. EDUARD FARBER.

Advanced Quantitative Analysis; Hobart H. Willard and Harvey Diehl. Pp. xi, 457; 40 figs. New York, 1943 (D. Van Nostrand Co., $4.75).—Elementary courses in analytical chemistry are necessarily subject to such limitations that the student spends most of his time acquiring quantitative technique through the performance of a number of simple determinations. The amount of chemistry learned in such a course may be very small, especially during the present war period when so much has had to be sacrificed to speed. In the opinion of this writer this is a most unfortunate circumstance for the chemistry major; he is not offered the opportunity of acquiring through his fingers as well as through his eyes and ears a working knowledge of the many and varied facts of inorganic chemistry. It is to be hoped that when leisure again becomes available for the digestion of knowledge, when the student is no longer forced to bolt his meals of science, our schools will offer advanced laboratory courses in inorganic chemistry for seniors and graduate students. No better way of learning inorganic chemistry is to be had than by the performance of a group of intricate inorganic analyses. Furthermore such a course would give to chemists, chemical engineers, and metallurgists a proper appreciation of the complexity of the problems involved in analytical chemistry, something they cannot possibly acquire from a sophomore course. The fundamental training in the varied chemistry involved in the complete analysis of a complicated mineral mixture such as bauxite is fully as valuable as the same time spent in the synthesis of a number of organic compounds.

The text of Professors Willard and Diehl offers to the teachers of inorganic and analytical chemistry a most excellent basis for the construction of such a course. The first third of the book is taken up by a discussion of general methods in analytical chemistry. Chapter I, starting with an apt quotation from Lundell on the distinction between analysts and "determinators," proceeds to such matters as the keeping of a note-book and the care of platinum. Chapter II, perhaps the most important section of the text, discusses problems and methods in the order in which they may appear in an analysis. An excellent discussion of the varied problems of sampling fills a gap probably left by most elementary courses. (The present writer once had impressed upon him the problems involved

in sampling by being assigned the chore of obtaining a representative sample from a hundred ton pile of nut coal. It was a dirty and instructive job. The nearest thing to a sampling problem arising in an elementary course might involve the grinding of two grams of a soft carbonate rock). Various solvents and preliminary decompositions are next discussed. There is an interesting section on concentration methods for the determination of minor constituents "such as the impurities of so-called 'chemically pure' substances." Incidentally, with the exception of colorimetry, of which there is an extensive discussion, the physico-chemical methods such as those of spectroscopy and polarography are not treated. To mention a few more of the topics there is a section on electrodeposition and a long section on the use of organic precipitants. For the theory of electrodeposition the reader is referred to the text of Willard and Furman. Considerable of the theory of organic precipitants is presented. These discussions alone illustrate very well the advantages to be gained in a discussion of analytical chemistry at the senior level. For any course in applied chemistry the basic courses in physical chemistry and organic chemistry should be prerequisite.

The second third of the text is devoted to laboratory directions, together with the necessary discussion, for "The Analysis of Iron Ore, Iron, and Steel," "The Analysis of Alloy Steels," and some parts of the methods used in the analysis of silicate rocks. The last third of the book contains discussions of the determinations of most of the elements not previously discussed. This section is built around the chemistry of the elements from the point of view of the periodic table. A chapter on the determination of atomic weights concludes the book.

This book has many excellent features as a text for the type of course in chemistry mentioned above. It serves as a bridge between the pure summary of Lundell and Hoffman and the extremely detailed work of Hillebrand and Lundell. One might perhaps better turn to these for reference purposes except insofar as the more modern character of the Willard and Diehl book is concerned; but as a text for advanced courses the latter is to be highly recommended. HENRY C. THOMAS.

GEOLOGY AND MINERALOGY.

Optical Crystallography; by Ernest E. Wahlstrom. Pp. iv, 206; 208 figs. New York, 1948 (John Wiley & Sons, Inc., $3.00).—This book is essentially a brief treatise on the principles of optical crystallography and their application to the use of the polarizing microscope. It was prepared primarily, according to the author,

as a text book for college courses in optical mineralogy, but can also be used as a handbook for investigators interested in using the technique in chemistry, metallurgy, ceramics, medicine, and other fields. A highly attractive feature of the book is the large number of text figures used to make clear the principles and applications. However, if Rinne's rule for determining the signs of interference figures had been given and explained, several pages of explanation might have been saved. F. Becke's accounts of the distinctive features that can be seen in certain interference figures (but which are never seen until they are pointed out) might well have been incorporated, but no text book has yet presented them in English.

ADOLPH KNOPF.

Minerals and Rocks: Their Nature, Occurrence, and Uses; by Russell D. George. Pp. xviii, 595; 150 figs., 48 plates. New York, 1948 (D. Appleton-Century Co., $6.00).—This volume is one of the Century Earth Science Series (Kirtley F. Mather, Editor), and is in essence a condensed treatise on economic geology, mineralogy, and petrology. It is intended to be used as a text book in second-year geology courses. Chapter I deals with the materials of the Earth and the physical properties of minerals, and includes a summary account of crystallography. Chapter II outlines the principles of the geology of the metalliferous ore deposits. These two chapters are evidently meant to serve as an introduction to the main matter of the book. Part I then follows, dealing with the metallic elements and minerals. These substances are described in the order of their industrial importance. Consequently iron (and steel) are considered first; general information on iron, pig iron, cast iron, and steel and alloy steels is given, followed by statistics of production and consumption. This information is followed by accounts of the "Iron Minerals Important as Ores" presented in the standardized form of mineralogy by giving composition, color, luster, crystallization, cleavage, etc.; then come the "Iron Minerals Not Important as Ores," which include so diverse an assemblage as marcasite, arsenopyrite, martite [important, however, as the chief ore mineral in the Krivoi Rog district, Russia], pharmacosiderite, chamosite [important as an ore mineral in England, Lorraine, and Newfoundland], and many others. After iron, steel, and the alloy metals have been described, the major non-ferrous industrial metals are discussed according to the same method, and so on for the other metals. A great amount of interesting information has thus been brought together.

Part II discusses the nonmetallic elements and minerals. In Part III the rock-making minerals are described, and in Part IV determinative mineralogy is presented. Finally, Part V deals

with the common rocks, closing with a valuable chapter on the industrial uses of rocks. Under one cover the broad fields of mineralogy, petrology, and economic geology, including industrial applications, are thus presented. Unfortunately, probably inevitably because the scope is more than one man can manage, inaccuracies have crept in at a number of places, suggesting that careful scanning by experts in the many fields covered would have been helpful. Beryllium is said to have notable properties as a steel-alloy metal, whereas actually when it is alloyed with copper it confers remarkable fatigue-resistance. The radioactive history of polonium as given on page 241 is far from true. It is somewhat surprising to read that "pyroxene is a calcium-magnesium iron silicate intermediate in composition and physical properties between diopside and hedenbergite"; that "chert is an impure calcareous flint"; and that dunite is defined as "a peridotite in which chromite is usually present"—a definition that leaves the essential features of dunite undisclosed. The scope of the petrology, especially of the igneous petrology, appears to be far too detailed in a book purported to be written on the sophomore or junior level. ADOLPH KNOPF.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Plants and Vitamins; by W. H. SCHOPFER, Director of the Botanical Institute, University of Bern. Authorized translation by N. L. Noecker. Pp. xiv, +, 298. Waltham, Mass., 1943 (The Chronica Botanica Co., $4.75). New York City (G. E. Stechert and Co.).—Ten years ago no book could have been written about vitamins in plants, although plants were clearly recognized as an important source of accessory factors for human and animal nutrition. During the past decade extraordinary progress made in the study of vitamins has resulted in a rich literature. The author's ambitious goal in writing this book is to crystallize our knowledge of vitamins in plants, to show the relations of this domain to general biochemistry and physiology, and to suggest fertile areas for cultivation by future investigators. The preparation of Plants and Vitamins required the consultation of a very extensive bibliography. It is a matter of regret that many interesting and important contributions mentioned briefly in the discussion are not cited by specific references to the literature. It is easy, however, to forgive omissions of literature since 1941, when one considers the difficult circumstances surrounding the author in Switzerland.

The contents of the book are organized into three parts. The first deals with the capacity for synthesis and the functions of vitamins in green autotrophic plants. In the second part, the author presents an extensive discussion of growth-factor deficiencies in organisms which have lost the ability to synthesize vitamins. Part

three describes some general phenomena which are wholly or partially explained on the basis of vitamin concept. Well deserved emphasis is given to the discussion of growth factors in microorganisms. There are twenty-four chapters not all of equal importance. There are author and subject indices, and many illustrations and structural formulae.

As stated by the author, his book does not by any means represent finality, but rather a stage of progress in research which continues to advance. A much improved classification of the B complex would be possible now. Although some workers may not wholly agree with certain interpretations of the literature and the emphasis placed upon various topics, this book fills the need for a critical and authoritative appraisal of the advancement of our knowledge concerning vitamins in plants.

The author points out how the vitamin problem began with observations on the nutrition of man and experimental animals, and that in recent years we have learned that the fundamental functions of vitamins are the same in regulating the metabolism of both plants and animals. The book indicates that at all phylogenetic levels, the requirements of living matter are approximately the same regardless of the structure of the organism. The only aspects that differ are the morphological expressions to which vitamin deficiency may give rise. The author shows how vitamins constitute the meeting ground for specialized sciences, where workers in organic chemistry, enzymology, human, animal and plant physiology all join forces to solve fundamental problems.

The philosophical viewpoint of the author is revealed in the following quotation taken from his concluding chapter. "In order to understand the problem of vitamins in all of its ramifications it is no longer possible to confine oneself to one field. The plant physiologist has learned from his confrère, the human physiologist, what an avitaminosis and a vitamin are. The plant physiologist in turn has shown that plants are the seat of the biosynthesis of vitamins and thus has established a new intimate relationship between two kingdoms. The biochemist, by establishing the chemical structure of vitamins, has been obliged to create new groups of chemical compounds. The enzymologist finds to his surprise that these vitamins are nothing but the active portions of enzymes which have been studied for a long time. The microbiologist, who for years had been trying, without success, to isolate the "growth factors" of his microorganisms, proved that typical animal vitamins were the factors he was looking for. The concept of growth factors (in the exact sense) conforms with that of vitamins (in the strict sense) and is identical with it."

"The problem of vitamins started with man and, in the last analysis, it returns to man after an apparent departure from him. All

the progress accomplished in this domain contributes to a better understanding of the problem in general and ultimately to human well-being. To speak of the well-being of Man at this time seems to be macabre humor. Why is it that skillful men from different nations can solve problems in fundamental biology but can not do so when the matter directly concerns themselves? The question remains unanswered." PAUL R. BURKHOLDER.

Galaxies; by HARLOW SHAPLEY. Pp. vii, 229; 126 figs. Philadelphia, 1943 (The Blakiston Co., $2.50).—This is the sixth volume to appear in the series of nine Harvard Books on Astronomy. As the title suggests, it deals with the star systems comparable with our galaxy. Our own Milky Way system is most decidedly included; in fact, one of the important features of the volume is that it stresses the comparative analysis of galaxies, demonstrating how knowledge of our galaxy may be used as a guide in the study of exterior systems, and how the latter aids in understanding our own. This method of approach is very fully employed in the second and third chapters, dealing with the Star Clouds of Magellan. The reader should receive a clear understanding of the nature of the problems, of their importance, and of the limitations imposed upon the astronomer by his telescopic equipment.

The author has contributed a major share toward the development of this relatively new branch of astronomy, both by his pioneer work and by his direction of research at the Harvard Observatory. No one is better qualified than he to write this survey.

DIRK BROUWER.

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THE 1840 ERUPTION AND CRYSTAL DIFFERENTIATION IN THE KILAUEAN MAGMA COLUMN.*

GORDON A. MACDONALD.

ABSTRACT. During the 1840 eruption of Kilauea volcano olivine basalt almost devoid of olivine phenocrysts was erupted from a group of vents at high altitude nearly simultaneously with the eruption, from a group of vents at low altitude, of picritic basalt containing abundant large olivine phenocrysts. The difference in composition between the lavas of the two groups is largely or entirely caused by the presence of the olivine phenocrysts in the picritic basalt. Gravitative crystal differentiation in the magma column appears to have produced an upper portion devoid of olivine phenocrysts from which were derived the lavas of the upper vents, and a lower portion enriched in olivine phenocrysts which supplied the lavas of the lower vents.

INTRODUCTION.

GRAVITATIVE differentiation by the settling of crystals through a magma is a well-established process, of which many examples have been described. The process has been shown to occur both in intrusive bodies and in lava flows, but examples of its occurrence in magma columns feeding volcanoes are rare, probably in large part because it is difficult to detect in such magma columns. At active volcanoes only the uppermost part of the magma column is directly observable, and at dissected necks of extinct volcanoes the vertical range of exposures is generally too small to reveal such differentiation. The demonstration of its occurrence in feeding pipes of active volcanoes must depend largely on a study of the lavas extruded, and is detectable only when the volume of the eruption, in relation to that of the feeding pipe, is so great that it largely empties the conduit, or when fissures simultaneously or nearly simultaneously tap the magma column at notably different levels. The 1840 eruption of Kilauea appears to have been

* Published by permission of the Director, Geological Survey, United States Department of the Interior.

one of the latter class, in which fissures tapped the magma column at levels sufficiently different to reveal the existence of crystal settling.

Several previously described examples appear to indicate crystal differentiation in the feeding conduits of volcanoes. These are briefly reviewed. In most examples of crystal differentiation at volcanoes, however, the differentiation probably occurred in the underlying magma hearth, rather than in the conduit of the volcano.

The writer wishes to thank Howel Williams, of the University of California, R. H. Finch, volcanologist in charge of the observatory at Kilauea, and H. T. Stearns, of the United States Geological Survey, for reading and criticizing the manuscript of this paper, and for valuable suggestions; and James Y. Nitta, who prepared the illustration.

The 1840 Eruption of Kilauea.

The eruption of Kilauea during May and June, 1840, was not witnessed by any trained observer. However, the Reverend Titus Coan gathered and recorded the accounts of natives who saw it, and the sites of activity were visited shortly afterward by Mr. Coan and by members of the United States Exploring Expedition, the latter including Lieutenant Charles Wilkes, the leader of the expedition, James D. Dana, its mineralogist, and Charles Pickering, its naturalist. The principal facts of the eruption and the distribution of the extruded lavas are, therefore, well substantiated.

The flank eruption was preceded by strong activity in the summit caldera, the entire area of which was occupied by liquid lava, said to be in violent agitation, "raging like old ocean when lashed into a fury by a tempest."[1] This condition continued for several days, but either just before or during the flank outbreak a great subsidence occurred which lowered the level of the lava in Halemaumau more than 300 feet.[2] The flank eruption commenced on May 30 with the appearance of liquid lava in Alae Crater (1, Fig. 1), a pit crater five miles southeast of Kilauea Caldera. The lava escaped from a northeast-trending fissure high on the northwest wall of the pit and cascaded to the bottom, where it formed a lava lake. Shortly

[1] Coan, Titus: 1841, Missionary Herald, vol. 37, p. 283.
[2] Dana, J. D.: 1890, Characteristics of volcanoes. New York, pp. 65-67.

afterward two other small flows escaped along the extension of the same fissure, one on the west and one on the north flank of the small lava shield, Kane Nui o Hamo (2, Fig. 1). At the same time or shortly afterward, other small flows were erupted between Makaopuhi Crater (3, Fig. 1) and Napau Crater (4, Fig. 1), and north and northeast of Napau Crater. Still another small flow was said to have taken place in the jungle several miles to the east of Napau Crater,[3] but its exact location is not now known.

Activity at the above-mentioned localities was short-lived, but fracturing continued eastward along the east rift zone of Kilauea toward Cape Kumukahi. Fissures a few inches to several feet in width opened, but with the possible exception of the small flow several miles east of Napau Crater, no lava reached the surface. Finally on June 1, two days after the outbreak at Alae Crater, the principal lava flow of the eruption commenced at a group of fissure vents near the present Pahoa-Kalapana road, 21 miles east of Kilauea Caldera and 16 miles from Alae Crater. A small flow developed west of the road, but the principal vents are east of the road, and are marked by low ramparts and small cones of spatter. Dana believed that the principal flow issued from fissures along its whole course, and these fissures are indicated on a map of the region by Wilkes.[4] True vents are, however, restricted to the upper part of the flow between the Pahoa-Kalapana and Pahoa-Kapoho road (Fig. 1). The fissures farther seaward, although in places bordered by small accumulations of spatter, are merely the traces of lava channels and collapsed lava tubes, as shown by their curvilinear courses and their divergence from the trend of all true fissures along the east rift zone. The lava issued as fluid pahoehoe and flowed northeastward. The earlier flow units remained pahoehoe all the way to the coast, but the later flow units, which in large part advanced over the earlier ones, in general changed to aa before they reached the coast.

On June 3, the lava reached the shore of Nanawale Bay, destroying a small village. For three weeks it continued to flow into the sea, heating the ocean water for 20 miles along the coast, killing thousands of fish, and building the shoreline outward about a quarter of a mile. Where the hot lava entered

[3] Dana, J. D.: 1849, Geology: U. S. Exploring Expedition, 1838–1842, vol. 10, p. 189.

[4] Dana, J. D.: Idem, p. 169.

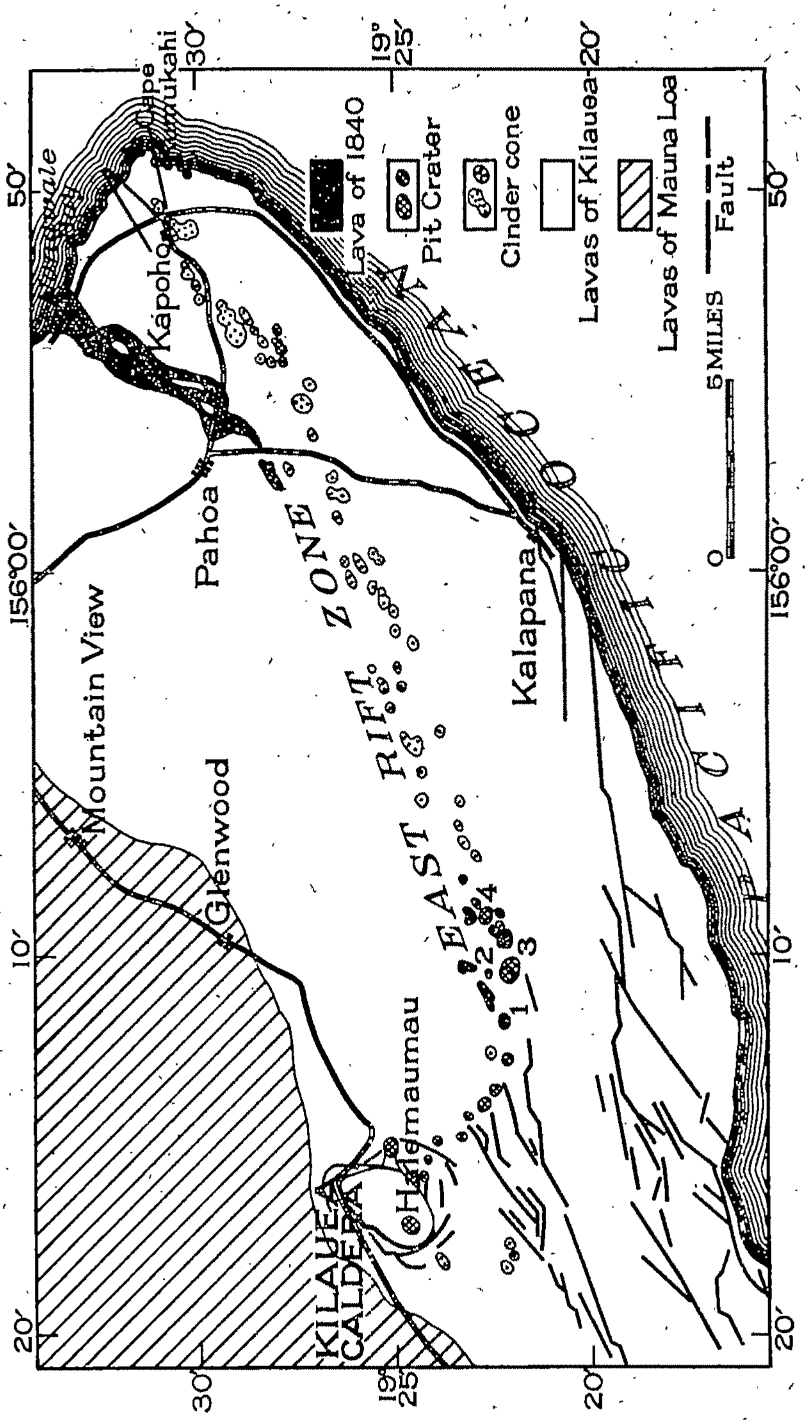

Fig. 1. Simplified geologic map of the eastern half of Kilauea volcano, showing position of the lava flows of 1840 (solid black). 1, Alae Crater; 2, Kane Nui o Hamo lava shield; 3, Makaopuhi Crater; 4, Napau Crater.

the sea, violent steam explosions occurred, blowing the liquid lava into a fine spray and pulverizing more solidified portions. The drops and fragments thrown into the air accumulated on top of the less active marginal parts of the flow, building hills of black glassy ash as much as 250 feet high[5] between which the main lava river continued to flow into the sea.

As in other occurrences of this sort, the strongest explosive action appears to have been produced by the aa portions of the flow. Pahoehoe lava is to some extent insulated by the glassy skin that rapidly forms on each advancing toe, and although large volumes of steam result when it enters water, the steam is not generated with highly explosive violence. The relatively quiet advance of pahoehoe into the sea was observed by Green during the 1859 eruption of Mauna Loa;[6] and although the entrance into the sea of the pahoehoe of the Matavanu flow on Savaii, British Samoa, caused steam explosions which built small hills of cinder, the activity was weak compared to that observed where aa enters the sea, as in the 1919[7] and 1926[8] eruptions of Mauna Loa. Along the shores of Kilauea and Mauna Loa all the large cinder hills of this sort, termed littoral cones by Wentworth,[9] are associated with aa flows.

The reason for the greater explosive activity occasioned by the entrance of aa into water is not difficult to understand. Aa has no continuous crust such as that of pahoehoe to act as an insulator. The fragmental nature of the surface of an aa flow allows the water easy access to the highly heated, still fluid interior of the flow, and presents to the water a very large surface area of hot lava. Explosively violent generation of steam is the result.

Petrography of the Lavas.

The vents of the 1840 eruption may be divided into two groups of considerably different altitude on the flank of the volcano. Those in the vicinity of Alae, Makaopuhi, and Napau Craters are at altitudes between 3,100 and 2,650 feet above

[5] Dana, J. D.: Op. cit., p. 190.

[6] Green, W. L.: 1887, Vestiges of the molten globe, vol. 2, p. 277, Honolulu.

[7] Jaggar, T. A.: 1919, Bull. Hawaiian Volcano Observatory, vol. 7, p. 133.

[8] Jaggar, T. A.. 1926, Idem, vol. 14, pp. 41-42.

[9] Wentworth, C. K.: 1938, Ash formations of the island Hawaii: Hawaiian Volcano Observatory, 3rd Special Rep., p. 22.

sea level, whereas the vents east of the Pahoa-Kalapana Road are between 850 and 750 feet altitude. The lavas extruded at the two groups of vents are markedly different in composition. Those from the lower group of vents are picritic basalts, rich in intratelluric phenocrysts of olivine, whereas those from the upper group of vents are olivine basalts comparatively poor in olivine and containing only rare olivine phenocrysts.

The positions of the small patches of lava on the east and west flanks of Kane Nui o Hamo (Fig. 1) were indicated on a map of the region made by Wilkes[10] only a few months after the eruption, and the identification of the lavas in the field, based on Wilkes' map and on the stage of development of vegetation on the flows, appears certain. Although the correspondence of the flows as mapped at the present time with the position shown on the early map is not perfect, it is sufficiently close, in view of the crude nature of the early map, to make one confident of the correctness of their identification. Wilkes' statement as to the time of eruption of the two flows shown on his map is positive and definite, and as he was accompanied by native guides well acquainted with the country, is almost certainly correct.

The identity of the lavas of the lower vents has long been definitely known, although the extent of the flow as indicated on the topographic map of the Kalapana Quadrangle is too great, and includes the flow that took place about 1790.[11]

Lavas from the upper group of vents have been studied in thin section, but no chemical analysis of them is available. The lack of a chemical analysis is not important, however, as the difference in composition between the lavas of the two groups of vents lies largely, if not entirely, in the content of phenocrysts. The lava flow that lies between Makaopuhi and Napau craters (3 and 4, Fig. 1) consists of olivine basalt pahoehoe. Rare phenocrysts of olivine, up to about 1 mm. in length, are present, but they constitute much less than one per cent of the rock. The groundmass is hyaloophitic, with an average grain size of about 0.05 mm. Microlites of olivine (six per cent), monoclinic pyroxene (24 per cent), plagioclase (20 per cent),

[10] Wilkes, Charles: 1845, Atlas, U. S. Exploring Expedition, 1838-1842, pl. 8. Brigham, W. T. 1909, The volcanoes of Mauna Loa and Kilauea. B. P. Bishop Mus. Mem., vol. 2, no. 4, p. 31.

[11] Macdonald, G. A.: 1941, Lava flows in eastern Puna. Volcano Letter, no. 474, pp. 1-2.

and iron ore (15 per cent), are imbedded in a glassy base (35 per cent). No olivine phenocrysts are present in the thin sections. The glass is black and opaque, owing to abundant iron-ore dust. Many of the olivine grains are skeleton crystals containing cores of black glass. The plagioclase is intermediate labradorite. The microlites commonly are arranged in a roughly radial manner about numerous centers, in the way described for other Kilauean lavas by Washington[12] and Stone.[13] Lava from the small flow west of Kane Nui o Hamo (2, Fig. 1) closely resembles that just described, except for the presence of plagioclase phenocrysts up to 4 mm. long and a few microphenocrysts of pigeonite and hypersthene. In some specimens, even those from depths of a foot or two below the top of the flow, black opaque glass is even more abundant than in the flow east of Makaopuhi Crater. In general, plagioclase phenocrysts form about two or three per cent of the rock, and the rare small olivine phenocrysts comprise decidedly less than one per cent.

The lava flow from the lower vents which entered the sea at Nanawale Bay has been described by Cross[14] and Washington,[15] but for comparison with the rocks of the higher vents it will be redescribed here. A specimen of the late aa phase from the sea cliff at Nanawale Bay is a dark gray rock containing very abundant phenocrysts of olivine up to 8 mm. long. In other specimens some of the phenocrysts are even larger, reaching a length of a little more than 1 cm. Many of the olivine phenocrysts are thinly tabular parallel to the side pinacoid, in the habit described by E. S. Dana,[16] and in sections cut normal to the tables they appear highly acicular, some measuring 2 mm. long by only 0.1 mm. thick. A few olivine phenocrysts are slightly rounded and embayed by magmatic resorption, but most are sharply euhedral, and all are entirely fresh. They

12 Washington, H. S.: 1923, Petrology of the Hawaiian Islands: III, Kilauea and general petrology of Hawaii. Amer. Jour. Sci., 5th ser., vol. 6, p. 344.

13 Stone, J. B.: 1926, The products and structure of Kilauea. B. P. Bishop Mus. Bull. 33, pp. 18-19.

14 Cross, Whitman: 1915, Lavas of Hawaii and their relations. U. S. Geol. Survey Prof. Paper 88, pp. 43-44.

15 Washington, H. S.: Op. cit., pp. 352-353.

16 Dana, E. S.: 1889, Contributions to the petrography of the Sandwich Islands. Amer. Jour. Sci., 4th ser., vol. 37, pp. 446-447.

Macdonald, G. A.: 1940, Petrography of Kahoolawe. Hawaii Div. Hydrog. Bull. 6, p. 154.

have $-2V=85° \pm$, corresponding well with the content of 81 per cent forsterite determined by chemical analysis by Aurousseau and Merwin.[17] A few microphenocrysts of feldspar up to 1 mm. in length are present, extinction angles on combined carlsbad and albite twins indicating a composition of labradorite-bytownite. A few grains of pigeonite also attain the dimensions of microphenocrysts, but grade in size into the groundmass. They are pale brown in thin section, with $+2V=45° \pm$. The groundmass is intersertal, with an average grain size of about 0.07 mm. It is composed of the following: labradorite (24 per cent), pigeonite (29 per cent), olivine (3 per cent), iron ore (8 per cent), and glass (7 per cent). The interstitial glass is heavily clouded with fine iron-ore dust. Other specimens both from the coast and from farther inland, are closely similar to that described above, although in one collected along the Pahoa-Kapoho road, five and one-half miles from the sea, the olivine phenocrysts are slightly altered to iddingsite around the edges, probably by gas action near or during the time of eruption.[18] In the same specimen the groundmass plagioclase was determined to be calcic labradorite ($\beta=1.566$).

The amount of olivine phenocrysts in the lavas from the lower group of vents ranges from about 25 to 35 per cent. The average, determined by micrometric analyses of three typical specimens, is 29 per cent.

The accompanying table shows the chemical composition of the lava at Nanawale Bay and of the olivine phenocrysts that it contains. Column 3 of the table represents the composition of the groundmass of the lava, and is derived by subtracting from the bulk composition of the lava (column 1) 29 per cent of olivine of the composition of the phenocrysts (column 2), and recalculating to 100 per cent. The resulting chemical composition is that of a normal basalt, which, despite the presence of normative quartz, might contain in the mode several per cent of olivine. This presence of olivine in lavas that show normative quartz is common in the Hawaiian Islands, and is probably the result of incomplete reaction between the olivine,

[17] Aurousseau, M., and Merwin, H. E.: 1928, Olivine: I. From the Hawaiian Islands; II. Pure forsterite. Am. Mineralogist, vol. 13, p. 560.

[18] Edwards, A. B.: 1938, The formation of iddingsite. Am. Mineralogist, vol. 23, p. 279.

Macdonald, G. A.: Op. cit., pp. 154–156.

Chemical analyses and norms showing relation of olivine basalt to picritic basalt.

	1	2	3	4	5
SiO_2	47.25	39.54	50.48	50.07	50.32
Al_2O_3	9.07	0.66	12.51	13.32	12.83
Fe_2O_3	1.45	1.08	1.62	1.92	1.74
FeO	10.41	10.37	10.28	9.28	9.93
MgO	19.96	46.57	9.09	8.01	7.39
CaO	7.88	tr.	11.10	10.64	11.06
Na_2O	1.38	0.46	1.76	2.16	2.38
K_2O	0.35	0.15	0.48	0.45	0.41
H_2O+	0.04	0.18	0.00	0.49	0.33
H_2O-	0.08	0.04	0.09	0.22	0.05
TiO_2	1.61	0.09	2.22	2.70	3.10
P_2O_5	0.21	n.d.	0.29	0.26	0.30
MnO	0.18	0.13	0.12	0.16	0.10
Cr_2O_3	0.12	0.13	0.11	0.05	n.d.
S	n.d.	n.d.	....	0.11	n.d.
NiO	0.09	a0.38	0.00	0.04	n.d.
Cl	n.d.	n.d.	....	0.08	0.04
Total	100.03	100.28	100.00	99.97	99.98
			Norms		
Q	...	...	2.10	2.16	2.04
Or	2.22	...	2.22	2.78	2.22
Ab	11.53	....	14.67	18.34	20.44
An	17.51	...	25.30	25.30	23.07
Di	16.65	...	22.62	20.83	24.28
Hy	18.12	...	25.54	21.06	18.43
Ol	28.17	b96.40	...	...	...
Mt	2.09	...	2.32	2.78	2.55
Il	3.04	...	4.26	5.17	5.93
Ap	0.34	...	0.67	0.67	0.67

[a] Includes CoO. [b] Includes forsterite 81.0 per cent, fayalite 15.4 per cent.

1. Picritic basalt, lava flow of 1840, Nanawale Bay. G. Steiger, analyst. Cross, W.: 1915, Lavas of Hawaii and their relations. U. S. Geol. Survey Prof. Paper 88, p. 44. Norm recalculated by Washington, H. S., 1923, Amer. Jour. Sci., 5th ser., vol. 6, p. 347.
2. Olivine from 1840 lava at Nanawale Bay. M. Aurousseau, analyst. Aurousseau, M., and Merwin, H. E.: 1928, Olivine; I. From the Hawaiian Islands; II. Pure forsterite. Am. Mineralogist, vol. 13, p. 560.
3. 1840 lava at Nanawale Bay, with 29 per cent of olivine of the composition shown in column 2 subtracted, and the whole recalculated to 100 per cent.
4. Olivine basalt, lava of 1894(?), floor of Kilauea Caldera. J. B. Ferguson, analyst. Day, A. L., and Shepherd, E. S.: 1913, Water and volcanic activity. Geol. Soc. Am. Bull., vol. 24, p. 586.
5. Olivine basalt, aa phase of lava flow of 1920, Mauna Iki. H. S. Washington, analyst. Washington, H. S.: Op. cit., p. 351.

which crystallizes out in considerable excess of its stoichiometric proportions, and the remaining magma.[19] For comparison, columns 4 and 5 of the table give analyses of two other historic lavas of Kilauea, both of which contain normative quartz and show a few per cent of olivine in thin section. In modal composition they are very much like the lavas of 1840 erupted from the upper group of vents. It is safe to infer that if an analysis of the 1840 lavas from the upper vents were available, it would not differ greatly from the analyses given in column 3, 4, and 5 of the table.

Other Examples of Gravitative Differentiation in Volcanic Conduits.

Certain other examples of extrusions that appear to indicate differentiation of the magma in a volcanic conduit may be briefly mentioned. During the outbreak of Sakura-jima in 1914, lavas were erupted from rows of vents on two sides of the volcano. Both groups of lavas were olivine-bearing hypersthene andesites, but those on the eastern flank were slightly more femic than those on the western flank. The principal difference lay in the consistent presence of olivine in the eastern lavas, that mineral being only sporadically present in the western flows. The difference in composition of the lavas was attributed by Koto to gravitative differentiation in the volcanic conduit, the fissure that fed the eastern vents presumably having tapped the main conduit at a lower level than that which fed the western vents. In addition, associated with the western lavas and occurring at the lateral margin and at the terminal front of the flows, there were slightly more salic lavas characteristically free from olivine, which were believed to represent the uppermost, first erupted, and most salic portion of the differentiated magma column.[20]

Composite lava flows in Renfrewshire, Scotland, described by Kennedy, consist of a lower portion of nonporphyritic basaltic mugearite grading upward into a porphyritic rock of similar groundmass composition but containing many large phenocrysts of labradorite-bytownite. The porphyritic rock is shown to have been extruded over the nonporphyritic rock at a slightly

[19] Washington, H. S. 1923, Petrology of the Hawaiian Islands; I. Kohala and Mauna Kea, Hawaii. Amer. Jour. Sci., 5th ser., vol. 5, pp. 469–470.

[20] Koto, B.: 1916, The great eruption of Sakura-jima in 1914. Tokyo Imp. Univ., Coll. Sci. Jour., vol. 38, art. 3, pp. 144–145, 176–187.

later date but while the nonporphyritic lava was still fluid. Some mixing occurred at the contact, plagioclase phenocrysts sinking a short distance into the underlying magma. Differentiation is believed to have occurred in the magma chamber or conduit, effusion commencing with the nonporphyritic magma that occupied the upper part of the chamber, and finishing with the porphyritic magma from a lower level in the magma chamber, which had been enriched in sunken phenocrysts.[21] Similar lava flows in Skye are believed to have had a similar origin, and it is suggested that the same general process may have operated in producing the variations in the 1910 lava flow of Etna.[22]

Another type of composite lava flow described by Kennedy consists of upper and lower portions of andesine mugearite, and a slightly later central portion of trachyandesite. The mugearite cooled most rapidly at top and bottom, leaving a still-fluid central portion that continued to flow. During the process of extrusion the composition of the magma changed from mugearite to trachyandesite, the latter following the fluid mugearite into the tube left between the chilled upper and lower portions of the mugearite, and reacting with the mugearite to produce a series of mixed rocks. It is suggested that the differentiation which produced the mugearite and trachyandesite occurred in the volcanic throat.[23] If the effusion took place from the summit vent, it would be expected that the upper, salic facies (trachyandesite) should have preceded the lower, femic facies (mugearite). Actually, however, the sequence was the opposite of this. It appears probable that a fissure tapped the magma column at a level occupied by mugearite, gradually draining the column from that level upward, and thus resulting in the sequence mugearite-trachyandesite.

Rittmann states that during periods of a clogged vent at Vesuvius, gravitative differentiation in the conduit results in the rising of light crystals of leucite, which accumulate directly beneath the plug, while heavy crystals of biotite, diopsidic augite, and calcic plagioclase sink downward in the magma.

[21] Kennedy, W. Q.: 1931, On composite lava flows. Geol. Magazine, 68, pp. 166-176.

[22] Idem, pp. 176-181.

[23] Kennedy, W. Q.: 1933, Composite auto-intrusion in a Carboniferous lava flow. Geol. Survey of Great Britain, Summary of Progress for 1932, pt. 2, pp. 83-93.

Succeeding plinian explosions hurl out these differentiation products and deposit them in inverse order on the mountain-side.[24]

Conclusions.

The 1840 eruption of Kilauea thus yielded two groups of lava flows of markedly different composition from two groups of vents of markedly different altitude. The lavas from the upper vent are olivine basalts practically devoid of olivine phenocrysts, whereas those from the lower vents are picritic basalts containing, on the average, 29 per cent olivine phenocrysts. The difference in composition of the rocks is, however, largely or entirely attributable to the presence of the olivine phenocrysts in the picritic basalt from the lower vents. Disregarding the phenocrysts, the remainder of the rock has a composition closely resembling that of the lavas from the upper vents.

The conclusion appears inescapable that the fissures that fed the upper group of vents tapped the upper part of the Kilauean magma column, whereas those that fed the lower group of vents tapped the magma column at a lower level. The erupted lavas differ in composition because of gravitative differentiation in the Kilauean magma column, which involved the settling of intratelluric phenocrysts of olivine, leaving the upper part of the magma nearly free of olivine phenocrysts, while a lower portion of the magma became enriched in olivine. The same process has probably been the mode of development of the many other picritic basalts of Hawaiian volcanoes, some of which contain only olivine phenocrysts, but many of which contain augite phenocrysts as well. It is possible that the plagioclase phenocrysts in the lava flow west of Kane Nui o Hamo are the result of flotation of crystals lighter than the enclosing magma, but the evidence is much less convincing than that pointing to the sinking of olivines.

Although fissuring of the ground was more or less continuous from the upper to the lower vents, it appears to have been largely a surficial phenomenon. The upper and lower groups of vents were probably not situated on a single continuous deep-seated fissure. If they had been so situated, opening of the fissure to the level of the lower vents should have resulted in

[24] Rittmann, A.: 1936, Vulkane und ihre Tätigkeit. Stuttgart, pp. 93, 97.

draining of the volcanic conduit to that level, and there should have been erupted some of the magma of intermediate composition which almost certainly existed in the conduit between the levels that fed the upper vents and those that fed the lower vents. This lava of intermediate composition has not been found. There appears to have been little extrusion in the area between the upper and lower groups of vents. It may be that the only actively eruptive portion of the magma was the lower portion, the wedging action of which opened a way for itself to the surface and also split the upper part of the volcano, allowing the magma that filled the upper part of the conduit and flooded the caldera floor to escape passively, forming the flows at the upper group of vents.

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APHELECRINUS, A NEW INADUNATE CRINOID GENUS FROM THE UPPER MISSISSIPPIAN.

EDWIN KIRK.[1]

ABSTRACT. A new crinoid genus, *Aphelecrinus*, is described. The genus has a long stratigraphic range, from the St. Louis to the high Chester. It also has a wide geographic range. One species from the upper Mississippian of Scotland is referred to the genus.

APHELECRINUS, new genus.

Genotype.—*Aphelecrinus elegans*, new species.

Crown. Moderately high, compact.

Dorsal cup. Turbinate to narrowly campanulate.

IBB. Large, forming an appreciable part of the wall of the cup.

BB. Large.

RR. Wider than high, large. Facet full width of *R*, linear. Suture gaping.

IBr. One in each ray, high, stout, constricted slightly medially.

Arms. Of medium length, moderately stout. Typically one isotomous division above the *IAx*. Among the described species no further division has been seen, but in one described and one undescribed species there are one or more sporadic divisions distad. The division above the main dichotom is high up, at from one-third to one-half the height of the arms. The *Brr* have slightly sloping faces in the earlier species, becoming cuneate in later forms. In one species the *Brr* in some cases fail to extend to the far side of the ramus. The pinnules are long and moderately stout. The $IIBrr_1$ are conspicuously long and in some cases, at least, bear pinnules.

Post IR. *RA* large, not penetrating deeply between *post* and *r post BB*. *X* large, extending well above the plane of the *RR*. *RT* smaller than anal *X*, the greater portion of the plate being above the plane of the *RR*.

Ventral sac. Extending to about one-half to two-thirds

[1] Published with the permission of the Director, Geological Survey, United States Department of the Interior.

the height of the arms. Reflexed and composed of numerous vertical rows of small, polygonal plates.

Column. Typically circular in section, with fairly well defined nodal and internodal series. One species referred to the genus has a subpentagonal column. The lumen is pentagonal to pentalobate.

Stratigraphic and geographic distribution.—*Aphelecrinus* has perhaps the widest stratigraphic and geographic range of any known upper Mississippian genus. In addition to the described species referred to the genus and the new forms here described, there are several undescribed species. Stratigraphically the genus ranges from the St. Louis to the high Chester. It is found throughout the Mississippi Valley areas of St. Louis and Chester and in Alabama and Kentucky. It is also identified in Scotland in beds correlated with the American Chester.

Relationships.—*Aphelecrinus* seems to be more nearly related to *Phacelocrinus* than any other described genus. It is interesting to note that the two genera are essentially coterminous as to their known stratigraphic and geographic ranges. The most obvious difference between the two genera lies in the structure of the arms. In *Aphelecrinus* there is a single primibrach that shows no signs of being compound. In *Phacelocrinus* there are two *IBrr*; and, even in later species where more or less complete anchylosis has taken place, the elements are recognizable. The arms of *Aphelecrinus* are relatively shorter and stouter than in *Phacelocrinus*. In *Aphelecrinus* there is an isotomous division of each ramus above the primaxil. In *Phacelocrinus* the rami typically do not bifurcate. In very late species of the genus an irregular sporadic branching of the arms is to be found in occasional rays. The column of *Aphelecrinus* is typically round, a subpentagonal section in the proximal portion of the column being seen in but one species. In *Phacelocrinus* the column is sharply pentagonal in section.

With the elimination of *Scaphiocrinus* of Wachsmuth and Springer (not Hall), all the species previously referred to *Scaphiocrinus* were supposed to be transferred to *Pachylocrinus*. *Pachylocrinus* is a well-defined genus. It has a depressed bowl-shaped dorsal cup, with the *IBB* within the basal depression. There are two *IBrr*. The arms in the earlier species have one or two isotomous divisions above the *IAx*. In the later and more typical species, however, there is devel-

oped an endotomous arm with several divisions. *Pachylocrinus* is a *Decadocrinus* with branching arms and no doubt is directly derived from that genus. There is no close relationship with such a genus as *Aphelecrinus*.

Species referred to the genus:

Aphelecrinus bayensis (Meek and Worthen), new combination.

Poteriocrinus (*Scaphiocrinus*) *bayensis* Meek and Worthen 1865, p. 157. "Chester, Bay City, Pope County, Illinois."

Poteriocrinus (*Scaphiocrinus*) *bayensis* Meek and Worthen 1873, p. 55, Pl. 20, Fig. 2.

Poteriocrinus (*Decadocrinus*) *bayensis* (Meek and Worthen) Wachsmuth and Springer 1880 p,. 119 (344).

Scaphiocrinus bayensis Meek and Worthen was described as bearing undivided arms above the *IAx*, but the distal portions of the arms are poorly preserved, and the division may not have been recognized. Wachsmuth identified a typical undescribed species of *Aphelecrinus* from Kentucky as *bayensis*. As he and Worthen were quite intimate, it is probable that this was a joint identification.

Aphelecrinus crassus Kirk, new species.

Plate 1, Fig. 11.

This species is represented by a single reasonably complete crown, weathered but in a fair state of preservation. It is described because of its large size and its apparently late evolutionary stage of development.

The crown has a height of about 80 millimeters, of which the dorsal cup takes up 12.5 millimeters. The crown is compact and is notable in the massive habit of the arms. With a height of 12.5 millimeters the dorsal cup has an estimated average diameter of about 16 millimeters. The cup is, turbinate, without apparent outward flare at the level of the radials.

The *IBB* are wider than high and form a closely united circlet approximately one-third the height of the cup. The *BB* average wider than high. The *RR* are large. On the articulating face the fulcral ridge extends the full width of the radial. The dorsal ligament fossa is narrow. The ligament pit is elongate, deep, and sharply defined. Owing to crushing, only *RA* is shown in the posterior interradius. The faces of the

plates preserved, however, show that the normal three-plate structure obtained.

The *IAx* is low and broad. The arms are long and unusually heavy. The second division of the arms comes at about one-fourth their height. The $IIBr_1$ is large. The next succeeding *Br* is much lower and is nearly rectangular in outline. Distad, the *Brr* are cuneate and in many cases fail to reach to the far side of the ramus.

Nothing is known of the ventral sac.

The column is circular in section, with well-developed nodals. The lumen is pentagonal in outline.

Horizon and locality.—The stratigraphic horizon of the specimen is unknown other than that it is Chester. The label merely reads: "Chester, Chester, Illinois."

Type.—The holotype is S 4439 in the Springer collection in the United States National Museum.

Relationships.—*A. crassus* most nearly resembles *A. okawensis* (Worthen). Both apparently come from the high Chester near Chester, Illinois. The figure of *A. okawensis* was made by Charles Worthen, who at best was an indifferent draftsman. However, it would seem that we are dealing with different species. In *A. okawensis* the dorsal cup has a decidedly convex outline as against the relatively narrow, straight-sided cup of *A. crassus.* In *A. okawensis* the *IBB* are relatively small and narrow. In *A. crassus* they are much larger and very broad. The arms of *A. crassus* are proportionally stouter than in *A. okawensis.* In *A. crassus* the brachials, particularly in the proximal portions of the arms, are high and tumid on the pinnule-bearing side, narrowing rapidly and in many cases not reaching the other side of the ramus. Nothing like this is shown in *A. okawensis*, though this could be explained as careless drawing.

Aphelecrinus dunlopi (Wright), new combination.

Pachylocrinus dunlopi Wright 1936, p. 401, Text-figs. 25-26, Pl. 8, Fig. 2.

Pachylocrinus dunlopi Wright 1939, p. 20, Text-fig. 12, Pl. 7, Figs. 1, 9.

In the Scottish upper Mississippian, Wright describes a crinoid that could well be referred to *Aphelecrinus.* This is his

Pachylocrinus dunlopi. The other species referred to *Pachylocrinus* by him are quite different types. *Aphelecrinus dunlopi* (Wright), new combination, has an irregular tertiary division of the arms. This structure, though not typical, would not exclude the species from the genus. It is a variant that should be anticipated and indeed occurs in at least one undescribed American species that I would refer to the genus.

APHELECRINUS ELEGANS KIRK, new species.

Plate 1, Figs. 6-8.

This form is one of the smallest and stratigraphically perhaps the earliest known species of the genus. It is, however, from a well-known horizon and is represented by 15 or more adequate specimens in the collections of the United States National Museum alone. For these reasons, and as it shows all the characteristic structures of the genus, it has been chosen as genotype rather than one of the later, larger species.

The series of specimens available for study shows a considerable range in size. As large collections have been made from this horizon over a long period of years, it is probable that the largest specimen represented, the holotype, is of about maximum size for the species. It is from this specimen that the measurements given hereafter have been made. The measurements are intended merely to give relative proportions and sizes of structural units and naturally vary among different individuals.

The crown of the largest specimen has a height of 33 millimeters. When not crushed the crown is of compact habit. The dorsal cup has a height of 4.4 millimeters and a maximum breadth at the arm-bases of approximately 6 millimeters. The cup is campanulate in shape, with a slight but well-defined outward flare at the level of the *RR*.

The *IBB* have an average height of 1.2 millimeters and a maximum breadth of 1.3 millimeters. The *BB* have an average height of 2.2 millimeters and a maximum breadth of 2.6 millimeters. The *RR* have an average height of 1.7 millimeters and a maximum breadth of 3 millimeters. In the *post IR, RA* is large, resting unequally on *post* and *r post BB*, with the larger face on *post B*. *RA* reaches to about one-half the height of *r post R*. Anal *X* is proportionally very large, fully half the plate extending above the facet of *l post R*. The *rT* is somewhat smaller than *X*.

The ventral sac is long and relatively slender. It is reflexed, and though the opening has not been seen, it probably lies at about half the height of the sac on the anterior side. The sac is somewhat flattened on the posterior side and reaches its greatest breadth at the apex. As the sac turns downward it becomes smaller, which gives the doubled portion of the sac a subtriangular cross section. At the base of the sac, on the posterior side, are at least two pairs of large tube plates. Distad there are four vertical series of plates. The tube plates are indented at their angles.

The arms are relatively short and stout. There is a single *IBr*, which is axillary. It is relatively large, having a height of 2.6 millimeters. Although somewhat constricted medially, it shows no signs of being compound. The *IIBrr*, as a rule, range from 8 to 10 in number. The first *IIBr* is large and clearly differentiated from the higher *Brr*. Distad the *Brr* have sloping faces and bear pinnules from the second *IIBr* onward. The pinnules are long and stout.

The column is circular in section, with a pentagonal lumen. The nodals are relatively high and wide, with rounded edges, clearly differentiating them from the internodal series.

Horizon and locality.—The principal locality for the species is about seven miles south of Huntsville, near Whitesburg, Alabama, on the ridge east of the road. The same horizon that has yielded abundant crinoids in the past is also found at the south end of the ridge west of the road. The horizon is called Ste. Genevieve in the Alabama State Geological Survey reports, but this age assignment is far from certain.

Types.—The holotype, S 4435a, and paratype, S 4435b, are in the Springer collection in the United States National Museum. The collectors of the types were Bernhardina and Charles Wachsmuth. The holotype is the specimen figured in Plate 1, Figs. 7 to 8.

Relationships.—*A. elegans* bears no close resemblance to any known species of the genus. It is the smallest known species of the genus excepting *A. scoparius*. From *A. scoparius* it differs in the campanulate cup, with outward-flaring radials, and the stout arms. In the shape of the dorsal cup it most nearly resembles *A. mundus*, from a much higher stratigraphic horizon. In the case of *A. mundus* we have a pentagonal column, hourglass-shaped *IAx*, and the second divisions of the rami fairly high up. *A. elegans* has a round column, *IAx*

slightly constricted medially, and the ramus division at a lower level.

APHELECRINUS LIMATUS KIRK, new species.

Plate 1, Fig. 10.

The specimen chosen as holotype of this species was figured by Springer (1926, p. 67, Pl. 16, Fig. 2) as *Pachylocrinus scoparius* (Hall). The species is described partly in order to rectify this error of identification and partly in order to illustrate an interesting variant in the structure of the ventral sac. Three other specimens have tentatively been assigned to this species. All are weathered, and accurate identification is not possible.

The holotype is a fairly young individual and still shows some juvenile characters. The crown of the holotype has a height of 40 millimeters, with a dorsal cup 5 millimeters in height and 7 millimeters in diameter. The largest crown referred to this species has a height of 75 millimeters. The crown is compact and unusually tall and slender.

The dorsal cup is turbinate, not showing the campanulate form so commonly found in the genus. The *IBB* are relatively small. The *BB* and *RR* are of approximately equal height. The plates of the *post IR* have the usual arrangement for the genus.

The *IAxx* of the holotype are proportionally large, a juvenile character. In any case the *IAx* is heavy and but slightly constricted medially. The first *IIBr* is large and bears a pinnule. This is probably true in other species as well but has not been seen clearly. The higher *Brr* are subcuneate to cuneate. The pinnules are long and stout. The arms are long and relatively slender. The second division takes place at about two-thirds the height of the arms in the holotype, as seen in two rays.

The ventral sac is reflexed and relatively short, being but approximately one-half the height of the arms in the holotype and much less in older specimens. As seen in lateral view the sac is very broad in its distal, redoubled half. In most species the sac seems to be more club-shaped. The sac is composed of numerous vertical series of small plicate plates. At the distal end are some subspinous plates.

The column is circular in section and composed of well-defined nodal and internodal series.

Horizon and locality.—The holotype and one other specimen

referred to the species were collected by Sidney S. Lyon at Grayson Springs, Kentucky. A third specimen bears a Lyon catalogue number that identifies it as from the Falls of the Rough. Lyon's pasted numbers came off readily in later years and, in the case of many specimens, are definitely misplaced. In the present case the lithology of the rock is very like that of Grayson Springs and very unlike any known specimens from the Falls of the Rough.

Types.—The holotype is S 2618 in the Springer collection in the United States National Museum.

Relationships.—*A. limatus* most nearly resembles *A. mundus*. *A. mundus* has a pentagonal column as against the round column of *A. limatus*. The dorsal cup of *A. limatus* has a smoothly convex outline as against the campanulate cup, with outward-flaring radials, of *A. mundus*. The *IAx* in *A. mundus* is sharply constricted medially. There is a very slight constriction in the case of *A. limatus*.

Aphelecrinus mundus Kirk, new species.

Plate 1, Fig. 9.

This species is based on a single well-preserved crown. The species is of somewhat less than medium size for the Chester forms. The crown measures 46 millimeters in height, with a dorsal cup 5 millimeters in height and with a maximum diameter at the arm bases of 8.5 millimeters.

The dorsal cup is campanulate, with a marked outward flare at the level of the *RR*. The *RR* are convex, giving the cup a distinctly pentalobate outline. The *IBB* have a height approximately one-third that of the cup. The *BB* and *RR* are of approximately equal height. The *RR* are relatively narrow. The *post IR* is concealed except for the *RA*.

The *IAx* is high, narrow, and deeply constricted medially. The *IAxx* of the *r post* and *ant RR* are notably longer than in the *r* and *l ant RR*. Though not seen, the *IAx* of the *l post R* would, of course, fall with the group having the greater length. There is an undescribed species from the Chester of Kentucky in which the *IAxx* have even greater disproportionate sizes. The higher brachials are for the most part cuneate in outline. Dorsad, each brachial is nodose, giving the arms a somewhat rugose appearance. The rami divide at varying heights. In the *ant R* the bifurcation takes place at above

one-half the height of the arm and in the *r ant R* at less than one-half its height. The arms of the *r post R* are not preserved to the division, but they carry on undivided to a height almost as great as that seen in the *ant R*. The pinnules are long and relatively stout.

Nothing is known of the ventral sac.

The small portion of the column preserved has been abraded. By grinding the distal end of the column a small portion embedded in the rock can be seen. This shows the column to be pentagonal in section.

Horizon and locality.—This specimen was collected by Sidney S. Lyon in the 1850's and bears his catalogue number 217. It came from the old locality at Grayson Springs, Kentucky. This horizon has been identified as Glen Dean, but this is open to question.

Type.—The holotype, S 4437, is in the Springer collection in the United States National Museum.

Relationships.—*A. mundus* most nearly resembles *A. limatus*. A comparison of the two is given under *A. limatus*.

Aphelecrinus okawensis (Worthen), new combination.

Poteriocrinus okawensis Worthen 1882, p. 24.

"Chester limestone; Okaw River above Chester, Randolph County, Illinois."

Poteriocrinus okawensis Worthen 1883, p. 296, Pl. 29, Fig. 2.

Scaphiocrinus okawensis (Worthen). Wachsmuth and Springer 1886, p. 286 (160).

Aphelecrinus oweni Kirk, new species.

This species is based on a complete crown of an individual of medium size, the crown of a larger specimen with a partial set of arms, a partial set of arms showing the distal portion of the ventral sac, and seven dorsal cups of various sizes, some with a few brachials attached.

The crown is of moderate height, the cup being approximately one-sixth the height of the crown in a specimen of medium size.

The dorsal cup is turbinate, with a maximum breadth somewhat greater than the height. The surface of the plates is papillose. The *IBB* form an appreciable part of the cup wall. The *BB* are large. *Post B* supports *RA* and *X* and extends upward to about one-half the height of *l post R*. *R post B*

supports *RA* in its upper left shoulder. The *RR* have a height somewhat less than that of the *BB*. The *RR* are strongly convex in their vertical axes, giving the cup a somewhat petaloid aspect when viewed from below or above. The radial facets are linear and extend practically the full width of the *RR*. The suture is slightly gaping. *RA* is large, reaching upward to above half the height of *r post R*. *X* is large, extending upward well above the level of *l post R*. *RT* is large, the greater part of the plate extending above the cup proper.

The rami are slender in younger specimens, becoming relatively stout in older individuals. The *Brr* have sloping faces in all stages, becoming sharply cuneate in later ontogeny. There seems to have been incompetent union between the *Brr*, for *IAx* is usually partially dissociated and shifted from its seat on *R*, and similar dissociation is to be noted as between consecutive *Brr* higher in the rami.

There is a single *IBr* in each radius. The *IAx* is proportionally stout and in medium- to large-sized specimens is slightly constricted medially. The $IIBr_1$ is conspicuously long, and the pair in each ray is in close contact laterally. The number of *IIBrr* seems to range from 10 to 12. No division of the ramus has been seen above *IIAx*. The pinnules are borne alternately by the *Brr* from $IIBr_1$, distad. The pinnules are relatively long and fairly stout.

The ventral sac is stout and composed of numerous vertical rows of strongly carinate tube plates. These plates in older specimens are marked by high carinae normal to the faces. The sac is reflexed. The ventral sac extends approximately to two-thirds the height of the arms.

In one specimen two columnals are preserved. These are pentagonal in outline, but it is probable that the column was circular in section distad.

The specific name is given in honor of David Dale Owen, pioneer in the geological explorations of Kentucky, as well as other regions, and an early student of the Crinoidea.

Horizon and locality.—Sidney S. Lyon collected the specimens in the 1850's from a locality known as Falls of Rough Creek, which lies on the boundary between Grayson and Breckinridge Counties, Kentucky. The locality is described and a section given by Owen (1856, p. 173). The specimens, judging by the lithology of the matrix and preservation, were collected on one horizon. The horizon is uncertain at present, but

it probably lies in the upper Chester. The horizon can be established easily when field work is done in the area.

Types.—The holotype, S 4436a, and paratype, S 4436b, are in the Springer collection in the United States National Museum. The specimens were originally in the Lyon collection as No. 190. As holotype I have chosen the specimen shown as Plate 11, Fig. 2.

Relationships. *A. oweni* bears some resemblance to *A. mundus*. *A. oweni* is a much larger species. The sides of the dorsal cup of *A. oweni* diverge more rapidly than in *A. mundus*, and the radials do not have the decided outward flare of the latter species. The *IAx* of *A. oweni* is slightly constricted medially, as against the hourglass shape of *A. mundus*.

Aphelecrinus randolphensis (Worthen), new combination.

Poteriocrinites (*Scaphiocrinus*) *randolphensis* Worthen 1873 in F. B. Meek and A. H. Worthen, p. 551, Pl. 21, Fig. 14. "Chester; Chester, Illinois."

Poteriocrinus (*Scaphiocrinus*) *randolphensis* Worthen. Wachsmuth and Springer 1880, p. 113 (338).

Aphelecrinus scoparius (Hall), new combination.

Scaphiocrinus scoparius Hall 1858, p. 680, Text-fig. 108, Pl. 25, Figs. 3a, b.

"Kaskaskia limestone, Chester, Illinois." (St. Louis limestone *fide* Worthen, 1882 and 1883.)

Poteriocrinus (*Scaphiocrinus*) *scoparius* (Hall). Wachsmuth and Springer 1880, p. 113 (338).

Non Pachylocrinus scoparius (Hall). Springer 1926, p. 67, Pl. 16, Fig. 2. (= *Aphelecrinus limatus*, new species.)

I have not been able to find the holotype of this species. However, in the Springer collection are two casts of the specimen, one of plaster and one of sulphur. They are both of indifferent quality, and, considering the small size of the specimen, little information is to be had from them.

The general habit of the crinoid, the single long primibrach, and the divisions of the rami seem to warrant the assignment of the species to *Aphelecrinus*.

It is to be noted that Worthen (1882, p. 17; 1883, p. 286) in a footnote states that this species as well as *Scaphiocrinus decabrachiatus*, *S. internodius*, and *Zeacrinus intermedius*, likewise described by Hall, were not from the Chester. He

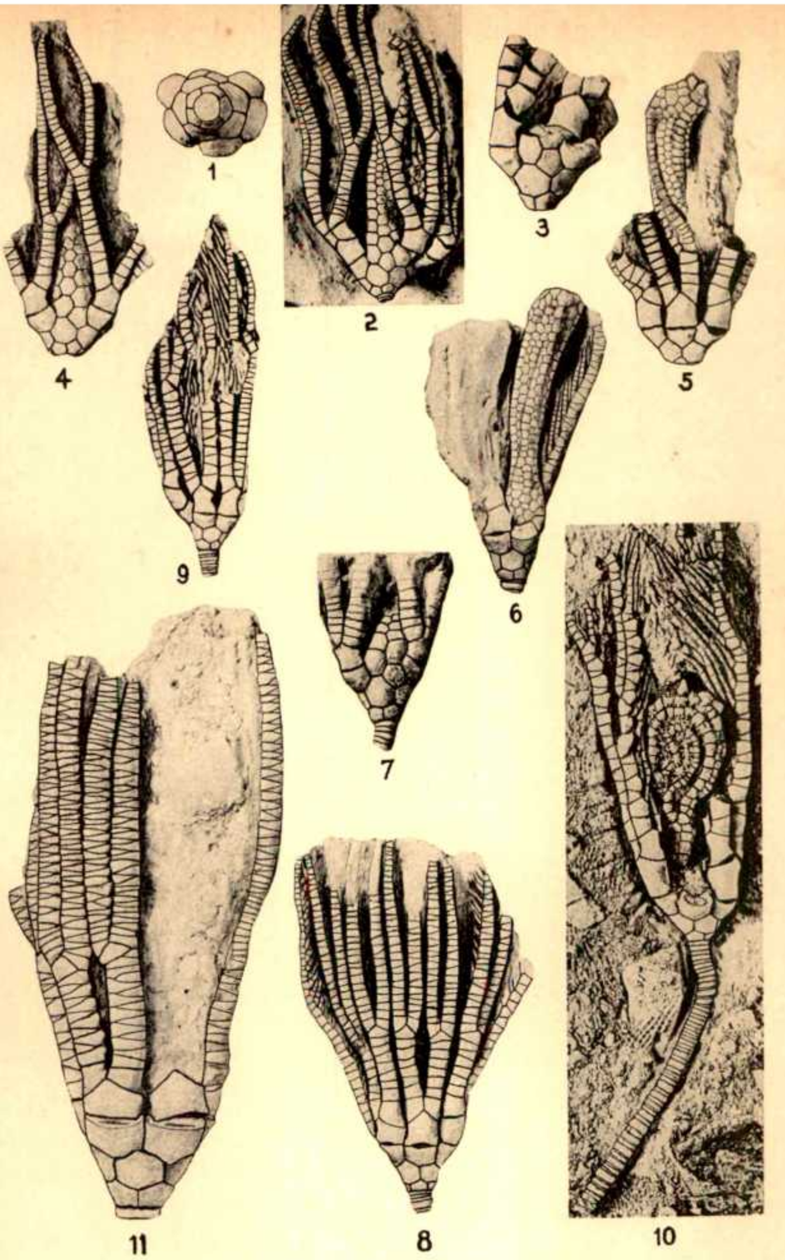

PLATE 1. APHELECRINUS

Figs. 1-3. *Aphelecrinus lyoni* Kirk, new species: 1, 3, basal and posterior views of paratype; 2, posterior view of holotype.
Figs. 4, 5. *Aphelecrinus simplex* Kirk, new species: 4, posterior, and 5, anterior views of holotype.
Figs. 6-8. *Aphelecrinus elegans* Kirk, new species: 6, left posterior view of paratype; 7, 8, posterior and anterior views of holotype. All figures x 1½.
Fig. 9. *Aphelecrinus mundus* Kirk, new species, anterior view of holotype.
Fig. 10. *Aphelecrinus limatus* Kirk, new species, anterior view of holotype, x 1½.
Fig. 11. *Aphelecrinus crassus* Kirk, new species, right anterior view of holotype.

states that he collected the specimens himself and that they were from the St. Louis limestone. It is impossible to resolve the problem at this time. Worthen was very accurate, and his statement should carry considerable weight. On the other hand, he may have been mistaken.

APHELECRINUS SIMPLEX KIRK, new species.

Plate 1, Figs. 4, 5.

This species is based on a single fairly well preserved crown. It is described because it shows a large part of the ventral sac and comes from a known locality in the Illinois Chester.

The crown is of medium size, with an overall height of 45 millimeters. The dorsal cup has a height of 5.5 millimeters and an estimated maximum diameter, uncrushed, of $10\pm$ millimeters.

The dorsal cup is crushed, but its general shape can be estimated with a fair degree of accuracy. The cup is lower and broader than in most species of the genus, and there is a pronounced outward flare of the *RR*. The cup, owing to the convexity of the *RR*, is distinctly pentalobate at the level of the arm bases. The *IBB* are relatively small and inconspicuous. The *BB* are also relatively smaller than usual. The *RR* are large and convex. *RA* is large, extending up to two-thirds the height of *r post R*. *X* is large, one-half reaching above the level of the *RR*. *RT* is larger than *RA*.

The *IAxx* are short, stout, and slightly constricted medially. The *Brr* are subcuneate to cuneate but always extend the full width of the ramus. The higher divisions of the rami take place at varying heights as seen. In *l post R* the divisions take place at about one-fourth the height of the arms, while in the *r post R* the division is much higher, at about one-third the height of the arms.

The ventral sac is long, reaching to more than three-fourths the height of the arms. *X* supports a plate on its truncate distal face, a large tube plate on its left shoulder, and *rT* on its right shoulder. Following these three plates distad as far as seen are vertical rows of large plates. As seen from the anterior side the sac is made up of several vertical series of small, hexagonal, plicate plates. The distal end of the sac is composed of a number of nodose to subspinous, heavy plates.

Horizon and locality. The locality as given by Fred Braun,

the collector, is "4-3/4 miles south-west of Floraville near Marteen School on road fording creek south of Waters Creek." This locality is in Monroe County, Illinois. This is in the Waterloo quadrangle. According to Springer, presumably based on Stuart Weller's authority, the horizon is Renault in the Chester.

Type.—The holotype is S 4438 in the Springer collection in the United States National Museum.

Relationships.—*A. venustus* (Worthen) comes from the same general region as *A. simplex* but, of course, might have been collected from quite a different horizon. The two specimens figured by Worthen as *venustus* and *peculiaris* may be young individuals. Nevertheless, the present species does not seem to be conspecific. The cup of *A. simplex* is relatively lower and broader than in *venustus*, and there is an outward flare of the radials that is lacking in *A. venustus*. The arms in *A. simplex* are relatively stouter.

Aphelecrinus venustus (Worthen), new combination.

Poteriocrinus venustus Worthen 1882, p. 24.

"Chester limestone; Monroe County, Illinois."

Poteriocrinus venustus Worthen 1883, p. 297, Pl. 29, Figs. 13a, b.

Scaphiocrinus venustus (Worthen). Wachsmuth and Springer 1886, p. 236 (160).

Synonymy.—

Aphelecrinus peculiaris (Worthen), new combination.

Poteriocrinus clytis Worthen 1882, p. 25 (*non P. clytis* Worthen 1882, p. 16).

"Chester limestone; Monroe County, Illinois."

Poteriocrinus peculiaris Worthen 1883, p. 298, Pl. 29, Fig. 10 (*nom. nov. pro P. clytis* Worthen 1882, p. 25, *non* p. 16).

Scaphiocrinus peculiaris (Worthen). Wachsmuth and Springer 1886, p. 236 (160) [cited as synonym of *S. venustus* (Worthen)].

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PETROLOGY OF TWO CLASTIC DIKES FROM THE PLACERVILLE DISTRICT, COLORADO.

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ABSTRACT. In this paper are presented the results of a petrologic study of two small clastic dikes from the vicinity of Placerville, in San Miguel County, southwestern Colorado. The geologic occurrence of the dikes, their clastic structure and the diversified composition of their lithic fragments suggest that the source of the material was the underlying pre-Cambrian terrane. Microscopic structures indicate that fragmentation and deformation were essentially contemporaneous with emplacement and accomplished by forcible intrusion.

INTRODUCTION.

IN the summer of 1942 portions of the vanadiferous Entrada sandstone, which is exposed in the upper reaches of the San Miguel River canyon, San Miguel County, Colorado, were mapped by a United States Geological Survey party in coöperation with the State of Colorado under the direction of Mr. Richard P. Fischer. In the course of this field work, which was confined essentially to the area between Placerville and Vanadium (Text Fig. 1), two coarsely fragmental clastic dikes were encountered.

Similar dikes from the Ouray area, approximately 20 miles east of Placerville, have been described in detail by Ransome (1900, pp. 227-236), Spurr (1923, pp. 843-849) and Burbank (1930, pp. 195-200). Near Ouray the field relations of certain large clastic dikes and some ore-bodies suggest significant control of mineralization by the clastic masses. Ransome and Burbank have emphasized the significance of these dikes as possible loci of ore deposition and their potential usefulness as guides in exploration. These writers also stressed the intrusive habit of the clastic bodies. Both concluded that the dikes must have been formed by forcible injection of fragmental material largely derived from source beds stratigraphically remote from the exposures examined.

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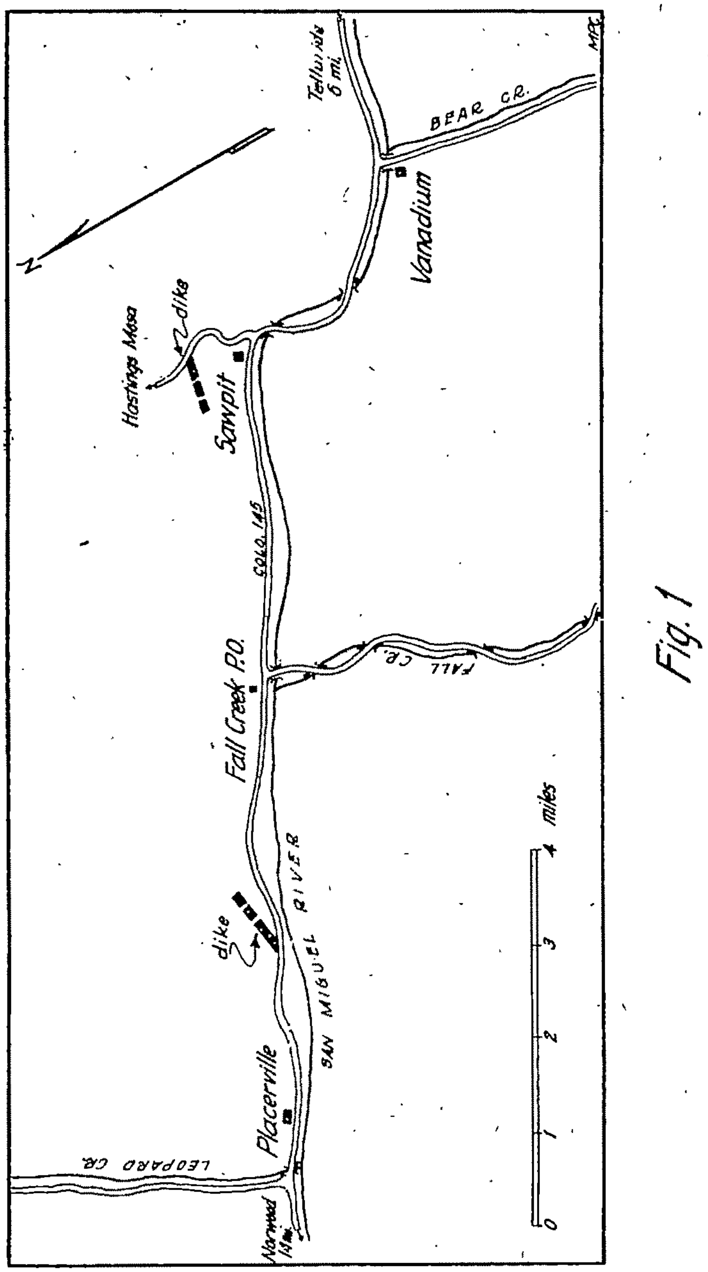

Fig. 1. Sketch map of the area around Placerville, Colorado, showing the approximate location of the clastic dikes described.

Study of the dikes from San Miguel County shows that their fragmental content is predominantly exotic in composition as compared with adjacent sedimentary rocks. As in the Bachelor mine near Ouray (Burbank, 1930, p. 197) the fragments in these dikes have apparently been derived from sources stratigraphically lower than the present exposures; on the other hand, the fragment assemblages in these dikes differ somewhat in lithologic character from those near Ouray for they consist largely of pre-Cambrian materials. Microscopic evidence indicates that the fragments in the Placerville dikes have been severely deformed and probably transported hundreds of feet vertically. Moreover, thin-section examination affords definite evidence that fragment deformation took place contemporaneously with, or very shortly after, emplacement. This hypothesis is further substantiated by the field relations which show that there has been no appreciable displacement of wall rock. Hence the petrologic data provide verification of the injection origin proposed by Burbank and, though differing in details, generally reinforce previous interpretations of comparable occurrences in the Ouray district.

GENERAL GEOLOGIC RELATIONS.

The Placerville district is a physiographically youthful, highly dissected portion of the Colorado Plateau. Deep, narrow canyons and precipitous slopes are characteristic and the available relief often exceeds 1,500 feet near the principal watercourses. Between the main drainage basins, the important one locally being that of the San Miguel River, are broad rolling mesas and forested uplands. Near Placerville the plateau is underlain by a thick series of nearly horizontal sedimentary rocks ranging from Permian to Cretaceous age. These rocks are predominantly coarse-clastic and shaly and constitute a thick accumulation of terrestrial and shallow-water deposits.

Approximately one-half mile northeast of Sawpit (Text Fig. 1) the sedimentary rocks are intruded by a dioritic stock, presumably of Miocene age (Cross and Larsen, 1935, pp. 105-106). Throughout the district are scattered a few thin but persistent diabasic and lamprophyric dikes. Normal faults, of steep dip and northwesterly trend and with displacement of 50-150 feet, occur at many places.

An abbreviated and generalized stratigraphic section for the Placerville area is given in Table I.

TABLE I.

Generalized Section of Formations near Placerville, Colorado.

	Feet
Upper Cretaceous	
Mancos shale	
Dark gray to black, thin-bedded, sandy shales	1200-1500 (plus)
Dakota (?) sandstone	
Massive, buff-colored, medium-textured, ferruginous sandstone with chert conglomerate at or near base	200 (plus)
Upper Jurassic	
Morrison formation[a]	
Alternating buff or gray, cross-bedded sandstones and greenish or purplish shales	575
Wanakah formation	
Marl member	
Predominantly purple or brownish, thin-bedded shale with irregular knots and lumps of calcareous material	85
Bilk Creek sandstone member	
Uniformly fine to medium-textured, light gray to white, massive sandstone	25
Pony Express limestone member	
Dense, uniformly fine-textured, unfossiliferous black limestone	10
Entrada sandstone	
Medium-textured, white or cream-colored, strongly cross-bedded sandstone containing frosted quartz grains	40
Jurassic (?) and Triassic	
Wingate (?) sandstone	
Thin-bedded fawn to buff-colored calcareous sandstone	10–20
Dolores formation	
Alternating brick-red, micaceous sandstones and ferruginous shales. Contains conglomeratic layers with rounded blue and brown limestone pebbles	600
Permian	
Cutler formation[b]	
Dark red or maroon sandstones and purple, fissile shales with lenses of conglomerate bearing cobbles of pre-Cambrian rocks	800 (plus)

LOCATION OF THE DIKES.

The smaller of the two dikes, hereinafter called the Sawpit dike, crops out 20-50 feet below the Hastings Mesa road at a point about three-quarters of a mile north of Sawpit (Text

[a] Goldman and Spencer: (1941, pp. 1745-1765), have subdivided the Morrison into four distinct parts, three of which are now classified by the Geological Survey as members of the Wanakah formation of pre-Morrison Upper Jurassic age

[b] Cross and Larsen: (1935, p. 30), assign a maximum thickness of 1500 feet to the Cutler formation in the San Juan region.

Fig. 1). This dike strikes N 80° W, dips 90° and ranges from 8 to 20 inches in thickness on the outcrop. At this locality the 30 feet of exposure available is sufficient to show that the dike cuts both the Dolores and the buff Wingate (?) sandstone underlying the Entrada. This narrow dike could not be traced upward into the Entrada which, near this locality, is well exposed in the roadway.

The larger and better exposed dike, here called the Placerville dike, crops out on Colorado State Highway No. 145, approximately half way between Placerville and Fall Creek P. O. It is exposed in a cut on the north side of the road as a light-colored dike 18 to 24 inches thick. This dike strikes N 80° E, dips 85° southward and cuts dark, reddish-brown Cutler sandstone. It can be traced continuously for over 500 feet in a general easterly direction, in which distance a vertical range of at least 200 feet of the dike is exposed.

DETAILED FIELD RELATIONS.

The contacts of both dikes against the enclosing sedimentary rocks are clean and sharp. There is no evidence whatever of exothermic effects in the adjoining rocks. No development of cross-cutting apophyses or of masses insinuated along the bedding of the host rock were observed. The outcrops are too limited to permit any generalization regarding the behavior of the dikes down the dip. In neither exposure could the slightest evidence of displacement of the strata in contact with the dikes

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PLATE 1.

Fig. 1. Photomicrograph taken to show the general fragmental structure of the Placerville dike, the jagged form of the clastic quartz and feldspar grains, and the dense, dark appearance of the carbonate and ferruginous matter in the matrix. Plane polarized light, mag. 85 x.

Fig. 2. Photomicrograph showing the variability in texture and structure of the Placerville dike. In this field most of the matrix is turbid carbonate. The colorless fragment near the bottom of the field is quartzite. On the right are three unaltered clastic feldspar grains. Plane polarised, mag. 85 x.

Fig. 3. Photomicrograph showing the typical angular outlines of the quartz grains and their general turbidity. The grain in the upper part of the field is transected by distinct micro-crevices. Placerville dike. Plane polarised light, mag. 85 x.

Fig. 4. This field contains a sericite phyllite fragment which has been almost completely replaced by carbonate along the original foliation planes. At the lower right is a grain of recrystallized limestone. The dark, nearly opaque character of the matrix is well shown. Sawpit dike. Plane polarized light, mag. 85 x.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

be found. No significant variability in the thickness of the Placerville dike was observed throughout the vertical extent visible. The Sawpit dike, however, pinches out vertically within less than 25 feet, although perhaps only locally.

A conspicuous feature of both dikes is the orientation of elongate and tabular lithic fragments whose long axes are habitually aligned parallel to contacts. It is the black shale, schist, and phaneritic igneous rock fragments that usually partake of this strong orientation. In the Sawpit dike there is appreciable variability, both in composition and texture, of the fragments within the restricted exposure. Whereas the lower part of this dike is congested with rock fragments, the upper part is a uniformly fine-textured aggregate of fragmental quartz and carbonate.

MEGASCOPIC CHARACTERISTICS.

The Sawpit dike is buff-colored and its fragments usually blend inconspicuously with the matrix. The groundmass aggregate is fine-grained and, because of admixed ferruginous material, darker than most of the lithic fragments. In this rock the lithic particles are elongate, well-rounded, of variable texture, and average 2 cm. in length. In addition, angular quartz grains and thin, platy, black shale fragments are conspicuous in hand specimen. The dense, fine-textured phase of this dike is darker than the rest and contains irregular calcite veinlets. Though rock fragments are lacking in this part of the dike it grades insensibly into the lower, coarsely fragmental portion.

As compared with the Sawpit rock the lithic fragments in the Placerville dike possess much greater diversification in both composition and structure. It is predominantly a light gray rock with a pinkish cast produced by the abundance of granitic fragments and isolated feldspar grains. The matrix of this rock closely resembles an arkose in appearance. This dike is relatively coarse-textured throughout as regards both matrix and lithic fragments. On the average the fragments range from 1 to 3 cm. in length although a few over 5 cm. in length occur sporadically.

Superficially both rocks resemble conglomerate much more than breccia because of the rounded outlines of the lithic frag-

ments. In an isolated specimen their general parallelism simulated bedding or imbrication as in a rudaceous sediment. The Sawpit rock is somewhat broken up by incipient shear planes which are closely spaced near the dike margins. The distribution and direction of these intermittent surfaces has been partly controlled by the size and shape of the fragments; hence the rock tends to break into slabs with hackly fracture, which, on the broken surfaces, show slickensided rounded depressions.

MICROSCOPIC FEATURES.

Microscopically both dikes have a well-defined fragmental structure (Pl. 1, Fig. 1) and consist predominantly of well-rounded lithic fragments and, by contrast, angular quartz grains, the latter ranging from 0.5 mm. to 2.0 mm. in cross-section. In addition to quartz, clastic grains of polysynthetically twinned plagioclase (Ab_1An_9), orthoclase, and microcline abound. Muscovite, biotite, and hornblende grains are also frequent, together with a few matted chloritic pseudomorphs after former mafics. Magnetite, pyrite, rutile, apatite, and a few tourmaline grains are common accessories. Most of the biotite is now very pale green, nearly colorless and only faintly pleochroic.

The matrix of the Sawpit dike is a relatively fine-textured complex of minute, angular quartz grains, opaque iron-oxides, and clay minerals, the whole cemented by carbonate and some chalcedonic quartz. This predominantly calcareous aggregate completely fills the interstices between the lithic fragments and clastic mineral grains. The iron-oxide is distributed in an exceedingly blotchy manner, although in a few places it tends to be localized along the contacts between clastic grains and matrix. The Placerville dike matrix is almost wholly crystalline carbonate (0.1-0.25 mm.) which is in places relatively euhedral and often forms rather coarse equigranular aggregates. This carbonate, though somewhat turbid, does not contain as much ferruginous matter as in the Sawpit dikes, but appreciable cryptocrystalline quartz is everywhere associated with it.

The fine-textured, calcareous phase of the Sawpit dike has a uniformly equigranular texture which, in places, is relieved by areas of more coarsely crystalline carbonate which was probably introduced along the veinlets. Minute, angular quartz grains are the principal clastic component, although occasional shreds of muscovite and chlorite, a few apatite and

tourmaline prisms, and disseminated magnetite grains also occur. Lithic fragments, even of very small dimensions, were absent in the sections examined. Finely crystalline carbonate and ferruginous matter also form the matrix of this variety. No clastic feldspar was observed in this phase, and in this respect also it differs markedly from the adjacent coarsely clastic portions of the dike.

The lithic fragments in these dikes embrace a wide lithologic range, for various plutonic and extrusive igneous rocks, metamorphic rocks, and sedimentary rocks are abundantly represented.

Most conspicuous among the sedimentary rock fragments are well-rounded, elongate grains of finely laminated red and black shale. It is certain that the red shale fragments are derived from either the Cutler or Dolores formations or both. On lithologic grounds it appears likely that some, at least, of the black shale fragments in the Sawpit dike represent brecciated portions of the Morrison, although part of them might possibly have been obtained from the Mancos. Fragments of fine-textured, non-fossiliferous limestone, some of them approaching true lithographic types, are perhaps most common among the sediments. A few grains of calcareous sandstone and occasionally one of chalcedonic quartz or chert also occur. The most probable source of the calcareous fragments in the Sawpit dike is the limestone conglomerates of the Dolores formation which it transects. It is more difficult to account for the limestone fragments in the Placerville dike. If it be assumed that some have been transported downward in the fissure, they could also be referred to the Dolores. On the other hand, the limestones of the Hermosa formation, which is nowhere exposed in the immediate vicinity, cannot be excluded as a source.

Elongate, fine- to medium-textured varieties of mica schist, commonly much modified, are most abundant among the metamorphic fragments. Sericite phyllite fragments, some of which still show blastoporphyritic quartz suggestive of their derivation from rhyolitic originals, also occur. The rarer, rounded quartzite fragments have typical mosaic structure and sutured grain contacts.

The igneous fragments in these dikes are of two principal kinds; phaneritic granitoid rocks of granitic, granodioritic, or perhaps monzonitic composition, and less commonly, rhyo-

litic and intermediate eruptives. Granophyre fragments in which the micrographic intergrowths are preserved are also present. In the Placerville dike fragments of devitrified spherulitic rhyolite, showing traces of spherulites and flow lines, are frequent.

With the exception of angular quartz grains, silicic phaneritic igneous rock fragments are most abundant in both dikes. Because of their relatively large size and coarse texture the details of their microstructure and mineral composition can be determined with more certainty than is the case with the other rock types. In the muscovite granite fragments microcline is without exception the principal feldspar, although some sodic plagioclase is almost always associated therewith. In the Placerville dike traces of myrmekitic intergrowths are preserved in some of the granite fragments. The feldspars are invariably the most modified minerals in the granites and usually are replaced by carbonate. Much of the microcline especially has been thus modified and in places selectively replaced along only one of the two grid directions.

Appreciable modification of other kinds of fragments in these dikes has ensued after incorporation. In the Sawpit rock many sericite phyllite fragments have been almost wholly replaced by carbonate (Pl. 1, Fig. 4). In some of these the mica alone has resisted carbonatization, thereby preserving traces of original foliation. It is quite probable that foliated metamorphic rock fragments were much more abundant originally than is now apparent and that many of the fine-textured calcareous fragments now present are actually pseudo-limestones. The evidence for this is so convincing, especially in those fragments in which peripheral replacement is incomplete, that it is most difficult to estimate the original bulk composition of these dikes with satisfactory accuracy. In the Placerville dike the rhyolitic fragments were especially susceptible to carbonatization. Such attack has proceeded from the grain margins where carbonate fringes, coextensive with the grain boundaries, can be seen penetrating the host and extending inward with development of randomly oriented calcite aggregates at the expense of the microfelsitic groundmass. As may be inferred from their structural characteristics many of these were originally fragments of glassy rocks which were subject to some devitrification prior to inclusion within the dike.

The only adequate source, in the writer's opinion, for the igneous and metamorphic rock fragments in these dikes is the pre-Cambrian basement complex beneath the Mesozoic and Paleozoic rocks. Throughout the San Juan region this pre-Cambrian terrane is known to include many varieties of granitic rocks, schists, and gneisses (Cross and Larsen, 1935, pp. 17-24). Unfortunately nothing is known regarding the rock types underlying the immediate Placerville area. The nearest exposures of pre-Cambrian are south of Silverton, some 30 miles southeast of the area here discussed. A possible source for some of the extraneous fragments might be sought in the coarsely conglomeratic beds of the Cutler formation. However, though some of these conglomerates are arkosic, for the most part those exposed near Placerville consist predominantly of intermediate eruptive rock fragments. The latter are only sparsely represented in the clastic dikes. It seems most likely therefore that the abundance of granitic and metamorphic fragments in these dikes indicates a pre-Cambrian source. On this assumption transportation of clastic particles to positions at least 1500-2000 feet higher than their source must be predicated.

STRUCTURES IN THE FRAGMENTS.

Isolated muscovite grains show the effects of deformation in two ways. Where situated between or near large rock fragments some mica grains are contorted and often arched conformably around adjacent lithic grain margins. In some places deformed muscovite flakes have been distorted so that the (001) cleavage lamellae are separated and divergent fan-wise near the grain boundaries.

Among the clastic mineral grains in these dikes it is the ubiquitous quartz which exhibits the greatest variety of microstructures. Much of it is exceedingly turbid because of minute included gas cavities and it is also often rutilated. Although these dikes are well indurated, and their fragmental constituents tightly packed and thoroughly cemented, the retention of angular outlines by the clastic grains denotes little, if any, encroachment upon them by matrix minerals.

The quartz grains also show the most pronounced fragmentation and strain effects. Many large quartz grains, though microscopically still structural units, have slightly varying optical orientation in different parts of the grain as is shown

by the irregular extinction. So far as can be determined this structure is quite analogous to that typifying "überindividuen" as that term is applied in petrofabrics. Other quartz grains show the ordinary uniformly undulose extinction, without containing separate areas within which there is unit extinction. Still other grains show micro-cracks although, rather unexpectedly, in these grains the individual areas with uniform extinction are not all coextensive with the separate parts of the grain as defined by the cracks.

A few of the larger quartz fragments are split open in a peculiar manner so that small crevices, which begin at the grain margins, converge and die out within the grain interior. These narrow crevices are filled with the usual calcareous substance constituting the matrix of the rock; in such shattered grains adjacent segments have diverse optical orientation. In grains possessing such cracks, divergent toward their margins, there is no evidence of sufficiently complete rupture to have produced measurable displacement of any part with reference to the plane of the thin-section. The original outlines of such grains, which are now interrupted by narrow re-entrants only, can be readily restored. They show absolutely no appreciable relative displacement of parts other than the divergent cracks which, though they do not cut wholly across the grains, are apparently adequate to produce the optical discontinuity shown by the variable extinction. It seems manifest that a structure of this kind could only have been developed essentially *in situ*. It is very difficult, if not impossible, to conceive of a fragment thus previously shattered remaining integral during transportation and emplacement of a forcibly injected mass.

In a few places there are found quartz grains which have been cracked through (Pl. 1, Fig. 3), but in which the constituent parts are not offset sufficiently to produce more than slightly irregular fragment boundaries. Stronger proof that much of this fracturing occurred during or only slightly later than incorporation of the grains is obtained where cracks, which can be traced continuously across intervening matrix, extend from one quartz grain on through an adjacent one.

Some fragments of coarse-textured muscovite granite have been sheared completely across. Their component parts are not widely strewn about through the rock but generally separated only by narrow matrix-filled channels. The boundaries of each part of a broken fragment are sharp and adjacent

pieces have corresponding outlines, thus indicating that dislocation was only nominal and, pertinently, that the smaller pieces are parts of one fragment which has been dismembered at or near its present position in the dike. In a few of these deformed granite fragments the quartz grains have been granulated along their contacts with development of typical mortar structure such as is associated with incipient mylonitization. These relations are believed to justify the conclusion that such fragments, like much of the quartz, were deformed during or shortly after intrusion of the clastic material.

CONCLUDING REMARKS.

There has been considerable discussion regarding the mode of origin of the clastic dikes occurring at several localities in the San Juan region. Ransome (1900, p. 233), in his description of the Bachelor mine north of Ouray, was the first to make a genetic distinction between *sandstone dikes* and others, like those here described, which he aptly designated *clastic dikes*. He applied the term "clastic" because of the prevalence in such dikes of lithic fragments of diversified composition and of the intrusive relations of the masses with respect to the enclosing rock.

In comparison with the clastic dikes near Ouray the San Miguel valley intrusives occupy a similar, though not strictly identical, stratigraphic position, inasmuch as they are also developed in Mesozoic and Paleozoic rocks. The Placerville dike transects the lower or middle part of the Cutler formation, which is stratigraphically several hundred feet lower than any heretofore reported for such bodies in this general region. This fact strengthens belief in the extension of such dikes to relatively great depths and their probable direct connection with pre-Cambrian source rocks.

Unlike the situation at the Bachelor and Steele mines there is no visible dislocation of the strata contiguous to the Placerville or Sawpit dikes. Their lithologic variability, therefore, cannot be generally ascribed, in whole or hardly even in part, to differential movement or kneading of fragments derived from adjacent beds. The range in composition of the lithic fragments and the preponderance of rock types foreign to any nearby source beds are believed to be adequate evidence opposing any assumption of their local derivation. Thus the lithologic diversity of the fragmental material, the apparent lack

of any adequate source rocks except at great depths, and the absence of even minor dislocation of the sedimentary rocks in contact with the dikes all converge to establish their intrusive origin.

Burbank concluded that the clastic dikes described by him from the Ouray district resulted from the violent intrusion of clastic material through forces engendered by gaseous igneous manifestations. He states (1930, p. 200): "it seems very probable that the injection of the clastic dikes was the result of a violent escape of volcanic gases and vapors and accompanying solutions, which had become temporarily trapped beneath an impervious blanket of sedimentary rocks." The dikes in the Placerville area provide no direct evidence, such as any unusual or suggestive hydrothermal alteration, igneous matrix materials, or mineralization, indicative of intimate connection with volcanic processes. They do, however, exhibit many internal structural features suggestive of forcible intrusion or injection, such as would be corollary to the origin proposed by Burbank. These features are summarized as follows: (1) although there is no evidence of faulting, the elongate lithic fragments are oriented parallel to contacts; (2) a parallelism of mineral fragments, which are aligned between lithic grains, signifies relative movement of parts of the clastic mass; (3) strain extinction is common in the fractured but only slightly displaced quartz; (4) the presence of contorted muscovite grains; (5) the fact that some granitic fragments have been fractured at or very near their present position, and (6) the presence of mortar structures in the quartz within these fragments all indicate considerable mechanical deformation, probably contemporaneous with emplacement. In the writer's opinion such evidence shows that formation of these dikes was accomplished by forcible intrusion into narrow available fissures. The microscopic data thus certify to a mechanism wholly compatible with the volcanic gas-phase activity hypothesis advanced by Burbank.

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SOME THOUGHTS ON THE EVIDENCE FOR CONTINENTAL DRIFT.

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A RECENT article by A. L. du Toit, entitled "Tertiary Mammals and Continental Drift" (1944), was prepared as a rejoinder to an earlier paper, "Mammals and the Nature of Continents," by George Gaylord Simpson (1943). I cannot presume to continue the debate on behalf of Doctor Simpson, since I have no qualifications in mammalian zoölogy and paleontology, and moreover I do not know what his reactions may be to particular points in du Toit's reply. However, Simpson is now serving in the armed forces of the United States, and probably he will have no opportunity to give further attention to this matter until the end of the war. In the meantime it seems desirable, for the good of geological science, to comment on some parts of du Toit's discussion that concern the concept of continental drift in general, and to offer suggestions for employing more comprehensively the type of critical study exemplified by Simpson's paper.

Simpson's discussion has two clear objectives: (1) to correct a number of gross errors that have appeared in published statements regarding mammalian distribution; (2) to use the established facts of mammalian distribution as a test in comparing the merits of three hypotheses concerning the geologic history of continents, including the concept of continental drift, known also as Wegener's "displacement hypothesis." At the outset Simpson clearly restricts his discussion to the evidence from mammals, with frank recognition that this evidence "is limited both in time and in scope. . . . It it not claimed that the mammalian evidence alone is conclusive for the Cenozoic or that if it were, the same conclusions would have to be extended to previous eras." This concentration on data in his special field, with exclusion of other data—however important in themselves—attention to which would obscure rather than clarify the immediate issues, is a highly commendable feature of Simpson's discussion. He is under no illusion that reëxamination of evidence in his limited segment of the problem can "disprove" the hypothesis of continental drift or "prove" any rival hypoth-

esis. It should be extremely helpful, however, to have each special aspect of this many-faceted subject examined critically by someone qualified to appraise that aspect. Unfortunately du Toit, in his reply, does not strictly respect this logical limitation of scope. True, he excuses his digressions on the ground that Simpson has failed to present some of his (du Toit's) views correctly, "or has omitted their other vital aspects." There seems to be no warrant, however, for du Toit's defensive plea, recurrent in his discussion, that Simpson "throughout his paper has entirely ignored the vital stratigraphic and tectonic aspects." Under any parliamentary procedure such comments would be ruled out of order, in view of Simpson's self-imposed restrictions in subject matter. Readers will be indulgent because of du Toit's open zeal for the concept of "drift," which he hastens to defend against every appearance of adverse criticism. Nevertheless his failure to restrict debate to subjects blocked out in the original paper serves to befog issues that should be kept clear, and makes his reply difficult to follow as a scientific analysis.

My good friend du Toit shows commendable spirit in acknowledging certain of his own errors that were pointed out by Simpson, and I am prone to dismiss on the ground of unconsidered phraseology some statements to which, appraised at their face value, one might justifiably take exception. In his introduction du Toit says that Simpson "has set out to prove that the evidence of mammalian distribution. . . is adverse to hypotheses of trans-oceanic or drifting masses, but favorable to current views of stable continents." Surely we are not reduced to the level of a college debating society, or of a court in law, in which each participant is interested only in making the best case possible for the "side" with which he is aligned! Regrettably there are scientists who, whether consciously or not, reveal a stronger interest in advocating chosen viewpoints than in objective appraisal of all pertinent evidence. Those who are familiar with Simpson's cool objectivity in scientific reasoning will only be amused at any suggestion that he is such an advocate. Careful reading of his paper in question brings conviction that he "has set out to" examine and evaluate data that have been cited regarding the distribution of mammals, and to draw such conclusions as these data seem to warrant.

Possibly some readers will have decided, on the basis of com-

ments up to this point, that I belong to the camp unalterably opposed to "drift," and that I am singling out for criticism items of du Toit's paper that are aside from any main issue. I should like to clear myself of suspicion on both these counts. The Wegener hypothesis has been so stimulating and has such fundamental implications in geology as to merit respectful and sympathetic interest from every geologist. Some striking arguments in his favor have been advanced, and it would be foolhardy indeed to reject any concept that offers a possible key to solution of profound problems in the Earth's history. On the other hand, critical examination and rigorous testing of the concept in all its aspects do not imply unfriendly opposition toward an unwelcome intruder into the realm of "orthodoxy." Intemperate statements have been made on both sides of the question; but these merely reflect weaknesses of human nature. Du Toit seems to sense a strongly intrenched opposition in what he calls "current geology, sublimely unconscious of its impotence." What is this "current geology," which apparently is synonymous with "orthodox geology"? I associate with numerous men in the science, and find them, on the whole, a rather open-minded group, not given to arrogant judgments on the many abstruse problems of the Earth, and emphatically not uniform in their thinking on these problems. They find much in their geologic work to occupy their attention aside from the conflicting hypotheses on the history of continents. However, thanks to recent published discussions most of them know the idea's on continental drift, and are willing to give these ideas a fair hearing. To be sure, most of them are not active protagonists of the hypothesis.

What should be done to improve the situation in "current geology"—other than to cultivate the open-minded attitude toward hypothetical matters in general and continental drift in particular? Du Toit states that he regards the hypothesis of drift "as essentially established by the Paleozoic and Mesozoic evidence." Does he mean *established as fact*, and would he have it taught among the established facts of geology? I fear that without more unequivocal evidence than we now can muster there would be many skeptics among the students. Perhaps he would be satisfied if numerous geologists entered into active and sympathetic discussion of the problem, treating it as a live issue in the science. I agree that this would be helpful,

provided the discussion were governed by rigid scientific standards. The concept of drifting continents will be strengthened only by establishing a body of incontrovertible evidence in its favor; not by reiteration of diffuse and qualitative arguments, some of them based on data that are subject to question. The foregoing statement may be pronounced a truism, but it is worthy of emphasis nevertheless, as Simpson's analysis of mammalian evidence makes amply clear.

Let us hope, therefore, that specialists in some other fields will emulate the example set by Simpson, by publishing critiques of evidence that comes within the range of their own competence. The result should be elimination of errors and other weaknesses from existing literature on the drift hypothesis, leaving a residue of data that can be accepted as dependable and significant. Simpson mentions certain erroneous statements and misinterpretations regarding reptilian distribution that appear in the literature on "drift." This is a large field, more critical in its bearing on the Wegener hypothesis than is mammalian distribution. Both Wegener (1929) and du Toit (1937) make much of the close resemblance between Triassic reptilian faunas found in South Africa and in South America. Simpson, reducing the available information to a quantitative basis, shows that 43 per cent of families and 8 per cent of genera are common to the two regions, with no identical species (1943). Du Toit replies that "the apparent lack of identical species among the Triassic reptiles of Brazil and South Africa should not strictly be pressed in view of the limited amount of collecting [and] the high ratio of new genera and species so far found. . . ." But Simpson is not *pressing* the lack of identical species—he is merely stating the facts now in hand. Significantly he, a close student of vertebrate faunas, finds in the evidence a resemblance between South America and Africa of such small degree that it "opposes a direct land connection, even a connection by a direct bridge." This verdict is indeed in sharp contrast with that of Wegener, who was neither biologist nor paleontologist, and with that of du Toit who, after naming about a dozen reptilian groups common to certain lands in the southern hemisphere, states: "These lists could be considerably amplified, but should suffice when taken in conjunction with the associated floras and the fresh-water fishes and mollusca, to prove the continuity of the various parts of Gondwana from the

Permian to the Rhaetic" (1937, p. 86). After studying Simpson's analysis of the reptilian evidence, the cautious reader will wish for equally expert advisers on the plants, the fishes, and the molluscs. When one is confronted with sweeping conclusions in these matters, truly a little learning is a dangerous thing.

Du Toit (1944) questions the validity of the percentage method for expressing fossil faunal resemblances, as it is used by Simpson, on the ground that "the recorded proportions of determinable genera and species could be very different from their actual frequency in nature. . . . The scantiness of such material cannot be overlooked nor the likelihood of unexpected discoveries that would appreciably modify current ideas." True enough; but is there any ground for supposing that a percentage of total forms common to two regions will be increased rather than decreased by future discoveries? The best we can do is to assume that known forms constitute a fair sample, and that *proportions* will not be radically altered even though the total may be greatly increased. Judgments, however tentative, must be based on evidence actually in hand. Surely expression of resemblances in the form of percentages gives a fairer overall picture of fossil faunas, and a more adequate basis for comparison with present conditions, than does a mere enumeration of genera or families whose distribution seems to harmonize with a given hypothesis of former land connections, to the exclusion of all other forms whose testimony is less favorable.

Du Toit emphasizes that mammals "have been robbed of much of their value through their late appearance on the scene, well after continental rupturing is deduced to have occurred . . ."; and goes on to reiterate his opinion of several years earlier, that "geological evidence almost entirely must decide the probability of this hypothesis, for those arguments based upon zoo-distribution are incompetent to do so." After an analysis of several inherent weaknesses in the paleontologic data he concludes that "the existing paleontologic evidence can be accepted only with reserve by those favoring drift." Each of these quoted conclusions seems reasonable, and all of them seem consistent among themselves. However, they appear somewhat strange against the background of arguments that are urged without any detectable reserve by all protagonists of "drift," for whom paleontologic and biologic evidence seems to

have a peculiar fascination. The high value placed by du Toit on the evidence from animals and plants bearing on the former "continuity of the various parts of Gondawana" has been cited on an earlier page. In like manner Wegener (1929, p. 101), agreeing with Stromer and others, tells us ". . . the distribution of the *Glossopteris* flora, the reptilian family of the Mesosauridae, and many other elements, makes necessary the assumption of a former great land mass uniting the southern continents." Authors of these positive statements do not warn readers that the biologic evidence is in any way equivocal. I find that college students who read the statements ordinarily accept them at face value and become convinced that a former close union of southern continents is demonstrated by the biologic evidence. Simpson has exposed the weakness of arguments based on the reptiles. Consideration of some problems presented by distribution of modern plants should give us pause also in accepting the strong claims based on ancient floras, including the famous *Glossopteris* flora. One example will serve as a cogent illustration.

Primitive dogwoods of the genus *Cornus*, containing about 40 species, and its near allies, are widely distributed in eastern North America, in southeastern Asia, and in groups of islands in the south Pacific (Fig. 1). "*Cornus* is conspicuously absent from both South America and the region of Australia—a fact which has a bearing in tracing the early migration of the family into the Pacific" (Brown, 1928, p. 3). Cretaceous representatives ranged continuously northward from central North America into the Arctic region (Fig. 1). Aside from the problem presented by the distribution in Asia, the occurrences in oceanic Polynesia are of unusual interest. How were the plants introduced from the probable center of origin in North America across thousands of miles of ocean, not to mention the additional barrier of intervening climatic zones? Brown suggests that during the early history of the dogwoods, when there was no land connection between North and South America, seeds were transported "in masses of buoyant drift such as separate from the delta region of the Mississippi. . . , and float for thousands of miles under the influence of the ocean currents and wind." In this way, aided by the equatorial drift, the dogwoods may have gained a foothold on one or more of the Pacific isles, whence they were further dispersed southward, step by

step, perhaps in part through the agency of birds. Distances between some of the existing islands are great, but some islands that were important in the dispersal may have disappeared during Cenozoic time. Further discussion of Brown's suggested solution has no place here; but it is worth noting that the distribution of the dogwoods poses greater problems than that of the *Glossopteris* flora, since it involves greater oceanic distances and more formidable climatic barriers. Moreover, the

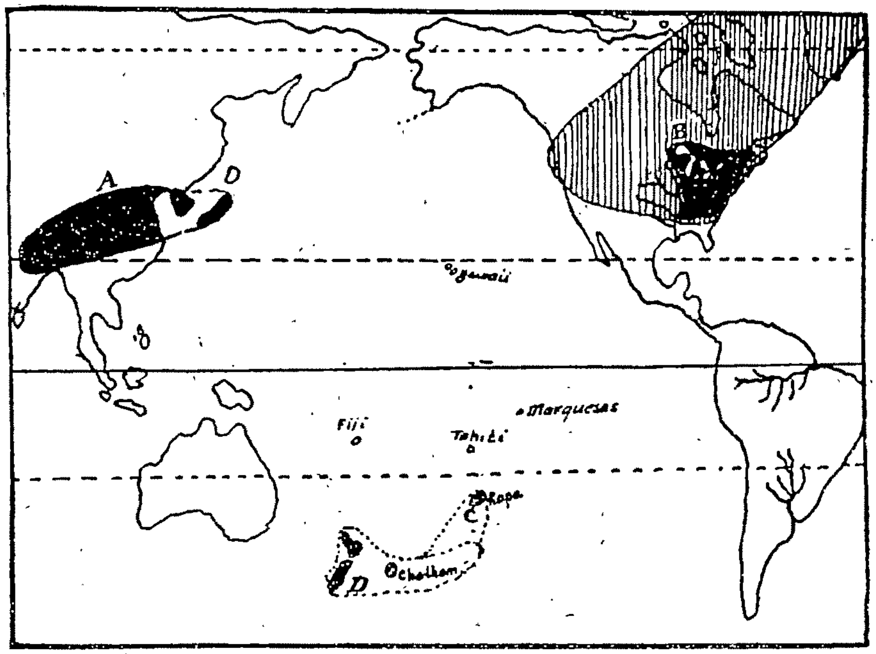

Fig. 1. Distribution of primitive dogwoods. Modern forms are found in the black areas (*A, B, C, D*). Known Cretaceous distribution shown by vertical lining. (Forest B. H. Brown).

hypothesis of continental drift does not help explain the dispersal of dogwoods—rather it increases the difficulties. Obscure ways in which plants and also some animals must have been distributed during long geologic time intervals are suggested by other examples from the vast Pacific region. When these numerous problems are viewed together, emphasis that has been placed on the *Glossopteris* flora as "compelling evidence" of once-continuous lands seems dangerously near the unscientific procedure of selecting evidence to support a favored theory.

There is no space here to discuss in detail the data from stratigraphy and invertebrate paleontology, although they deserve analysis by expert students. The stratigraphic data are, perhaps inevitably, diffuse and difficult to evaluate. Du Toit's arguments for the "Samfrau" geosyncline, extending from Argentina through South Africa to eastern Australia, are not easy to follow, although he tabulates much of the information in a stratigraphic chart which in his judgment shows an "extraordinarily similar sequence of events" in the regions concerned (1937, p. 62). Stratigraphers will ask what degree of uniformity is to be expected throughout a geosyncline extending at least 110 degrees in length—a question that is pointed by diverse formations of equivalent age in the shorter Appalachian geosyncline. In considering the "striking similarities" between stratigraphic units on opposite sides of the Atlantic, we should keep in mind that Nature has a strange way of producing near-duplicates, either in widely separated regions or in the same region at different times. Parts of the Torridonian sandstone of Scotland might well be mistaken for Old Red sandstone in the same small country if evidence of the stratigraphic sequence were lacking. Du Toit meets the argument that "drift" would require near-identity of facies and faunas on opposed coasts by assuming an original distance of several hundred kilometers between present shorelines of South America and Africa. This device has the twofold effect of avoiding certain difficulties and of admitting that the case for "drift" based on stratigraphic similarities is less convincing than a protagonist might wish.

The most striking unit in du Toit's "Samfrau" belt consists of late Paleozoic glacial deposits; and without question the eloquent testimony that widespread ice caps reached to low latitudes in the southern continents furnishes the most cogent argument that has been offered in favor of continental drift. The marvelous displays of this evidence, particularly in South Africa, serve to create in the geologist a humble attitude and a feeling of tolerance toward all attempts to explain this great enigma. Students of climatology do not agree on the significance of the evidence, however; G. C. Simpson interprets it in favor of continental drift, but Brooks points out other possibilities (G. C. Simpson, 1930).

With regard to tectonic evidence, on which du Toit lays special emphasis, students of structure are not prepared to agree on any sweeping conclusions. Many of the structural features cited in favor of "drift" are in regions of complicated geology that are known from reconnaissance studies only. Du Toit (1937, Fig. 13) shows structure-lines on opposite sides of the Atlantic that seem to match in most convincing style, until the reader learns that the lines represent approximate axes of broad regional uplifts dated as "post-Triassic"—surely not features that can be correlated with exactness in either space or time. Some of the structural data on which Wegener based plausible arguments were shown to be erroneous (Lake, 1922), but were cited again several years later as if they constituted valid evidence (Wegener, 1929, p. 77). Remarkable similarities are reported between the Cape Ranges of Africa and the Sierras of Buenos Aires in Argentina, and the northern end of the Appalachian belt of folding can be made to fit in striking fashion against the western termination of "Armorican" folds in the British Isles. Definite data of this kind of course arrest the attention of all serious students of tectonics, and establish the "drift" concept among the hypotheses that must serve as equipment in the present nebulous stage of megatectonics. Many of us, however, are not yet prepared to accept literally Wegener's interesting analogy of the torn newspaper as applied to Atlantic coasts, nor to entertain his extravagant suggestion—offered, it is true, with some reservation—that the geologic "controls" make his assumption of continental drift probable by odds of the order of a million to one (1929, p. 79). Structural data must be vastly amplified and much refined before they can provide the basis of any satisfactory comparison between opposed coasts of the Atlantic.

If I were free to select the next block of subject matter related to continental drift for an expert audit, my choice would be the several redeterminations of geographic coördinates carried out in the effort to detect relative shifts of continental masses that may be now in progress. These projects have special appeal and importance, since they offer the possibility of demonstrating, within the present generation, actual horizontal movements of the kind envisaged in the drift hypothesis. Results of the several projects were reviewed by both Wegener (1929) and du Toit (1937). Data from Greenland and vicin-

ity have come from comparison of longitude determinations at several dates in the nineteenth century with more recent determinations at the same stations. The older work used observations of the Moon, whereas some of the later values represent modern methods, using stars in combination with radio time-signals. All of the results cited indicate westward movement of Greenland (and of Jan Mayen), at average rates that range from 4 to 25 meters per year. Wegener admits—more freely in the fourth than in the third edition of his book—the possibility of rather large systematic errors in the determinations based on observations of the Moon. How seriously does this factor impair the values on which the apparent movement rests? Du Toit (1937, p. 300) remarks that even if all the measurements referred to above be rejected, we still have two modern determinations at one Greenland station, with an interval of five years, which indicate westward movement at the rate of 36 meters per year, a figure "far in excess of the probable errors." The skeptic with only moderate qualifications in mathematics will answer promptly that a single example cannot be accepted as the basis of a confident conclusion, since conceivably it may involve errors several times the theoretical probable error.

Wegener emphasized that all of the results indicate westward movement, and that this would imply an extraordinary coincidence of systematic errors in several independent determinations. This argument is weakened by consideration of additional data. Littell and Hammond (1928) published a determination in 1927 of difference in longitude between Paris and Washington, and compared the value with that obtained in 1913-14. According to the figures, the distance between the two stations increased in the 13-year interval by 4.35 m. ± 1.0 m., or about 0.32 m. yearly. This result came to Wegener's attention while the last edition of his book was in press, and was included in a special appendix (1929, p. 220). Du Toit quotes the figures (1937, p. 300), but does not report a damaging refutation from Sir Frank Dyson, Astronomer Royal at the Greenwich Observatory, who stated that comparison of longitude values at Greenwich and Washington between 1913 and 1926 indicate a *decrease* of distance by more than 9 m., an average of about 0.7 m. per year (*Nature*, v. 124, 1929, p. 649). These contradictory results make it appear

that the possible error of such determinations is at least several meters, at old established stations using the most refined modern methods. Since conditions for observations in Greenland are far less satisfactory at best, and since all but one set of available data involve to some extent the inaccurate lunar method, objective judgment can hardly indorse du Toit's statement, "it must therefore be concluded that a positive shift of crustal matter has been instrumentally observed." Why should we be hasty in reaching conviction in this matter? Modern methods of determining coördinates are closely accurate and will eventually reveal the truth. Jensen's Greenland station of 1922 can be reoccupied after the war, and the interval of more than 20 years should give a far better basis for judgment than any Arctic data now available. Even if future observations in this century should fail to indicate appreciable movement of any land masses, the hypothesis of continental drift would still be tenable, since movements may have been episodic, or at rates too slow to be detected within a human generation. To du Toit, after a review of the instrumental work in Greenland, "The reluctance of so many persons to concede the probability of such movements is hard to understand. . . ." (1937, p. 300). I have no personal aversion to westward movement of Greenland—in fact I should be pleasantly excited by the vista of tremendous implications attendant on authentic confirmation of such movement. However, in this matter we are not dealing with *probabilities*. Astronomers and geodesists will eventually tell us that observations either have or have not demonstrated a shift of Greenland with relation to Europe. Until that time the only objective attitude is one of "wait and see."

Perhaps it is inevitable that the early stage of testing a revolutionary concept, such as continental drift, begets some harsh critics and also some advocates with partisan zeal. Surely the time has come to treat this subject objectively, and to separate wheat from chaff in the voluminous argumentative literature devoted to it. Du Toit says, reasonably enough, "Critics of Continental Drift are apt to forget that this conception. . . is still being shaped and must experience revisions and modifications during its evolution." On the other hand, friends of the concept must expect that scientists generally will submit all aspects of it to close scientific scrutiny.

If the concept is fundamentally sound it will survive all such tests; any parts of it that fail under scientific testing are not worthy of survival. It does not help the cause to accuse all its critics of "orthodoxy," with the implication that this state of mind is as unworthy as fascism. Protagonists of "drift" should welcome all searching study of the evidence by competent experts. Moreover, these protagonists would serve their cause by attempting to purge their own contributions of obvious weaknesses, since they have a human audience, endowed with limited time, patience, and objectivity. Soon after the appearance of Wegener's well-known book in the 3rd edition, I heard a prominent geologist who was sympathetic toward the drift hypothesis remark, "Wegener's book is at least 50 per cent dross, but it contains also some pure gold for anyone who looks for it honestly." Other readers, less objective, were repelled by the numerous obvious flaws in Wegener's presentation, and condemned the entire concept out of hand. Particular exception has been taken to one of Wegener's "geologic controls," which to the last he rated equal in value with mountain axes and other major features of the bedrock; namely, the late Pleistocene terminal moraine in Europe and North America, supposedly broken and the parts separated by westward drift of the latter continent. Du Toit rejects this part of Wegener's scheme, on the ground that it involves "an absurdly late date for the main movement under which those continents became separated." Indeed, Wegener appears to have forgotten entirely the Rocky Mountain deformation and other pre-Wisconsin tectonic episodes of the North American Cordillera, which he himself related to westward movement of the continent. Charitable commentators suggest that such inconsistencies may be overlooked on the ground that Wegener was not a geologist. However, his view regarding the terminal moraine is curiously vulnerable from the viewpoint of climatology, which is related to his own subject. He notes that the American moraine now enters the Atlantic fully four and a half degrees south of the moraine in western Europe, and thinks it more logical to have the moraines brought to the same latitude by his reconstruction which moves America northward. However, since at the present time annual isotherms are 10 or 12 degrees farther south in eastern North America than in western Europe, why is it difficult to believe that the ice cap reached farther south on the west side of the Atlantic?

Du Toit has a revised version of the Wegener hypothesis which omits some glaring defects in the original. However, du Toit also is guilty of curious weaknesses which bring his effort into disrepute with some readers. As an example I quote the following passage, which is an attempt to explain certain tectonic features as the consequence of northward migration of the two postulated parental land masses: "Laurasia in moving from its more or less equatorial position towards the North Pole— where the meridians were *convergent*—became subjected to an E.-W. *compression*, revealed in its orogenies from the Carboniferous onwards and especially in that of the Urals, whereas Gondwana moving towards the equator—where the meridians were *divergent*—became put under *tension in an east-west direction*, which ultimately led to its fracturing and wide dispersal. Such would explain the vital difference, why, in contrast to their similar "equatorial" and peripheral crumplings, *Laurasia should display dominantly meridional folding but Gondwana meridional rifting*." (1937, p. 305). The reader may well rub his eyes and ask whether the author offered these suggestions seriously. The suggested mechanism could be made credible only by proposing a plausible force, powerful in its operation, which urged every molecule of all land masses, on both sides of the equator, inexorably toward *one point* near the north geographic pole. Shall we invoke terrestrial magnetism as a possible cause of orogeny? It is true that such lapses from the plane of objective analysis do not affect the merits of the basic concept of "drift." However, an avowed protagonist presumably sets out to win his readers to his own views, and should try to avoid destroying their confidence instead. The case for continental drift deserves more discriminating presentation.

The frankly critical tone of this brief discussion may brand it as an unfriendly attack in the eyes of proponents of the "drift" concept. Zealous believers commonly follow the motto, "He that is not for us is against us." However, I have devoted time to the discussion only because of a genuine interest in the hypothesis of continental drift. I have an interest also in some other hypotheses designed to explain major features of the earth in terms of its history. No one of these hypotheses has yet won me as a protagonist, and at present it is inconceivable to me that any scientist could adopt one such hypothe-

sis to the exclusion of all others. Perhaps a definite choice of creed brings some peace of soul that is denied to the scientific skeptic. However, those who declare unswerving loyalty to any hypothetical concept appear to settle into an "orthodoxy" of their own, which interferes with breadth of scientific vision. In the genetic study of major earth-features I can not believe we have arrived at a stage that permits discarding the method of multiple hypotheses. In this study the several concepts at our disposal are essential tools, which should be sharpened continuously with the abrasive of objective criticism.

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CYMBIOCRINUS, A NEW INADUNATE CRINOID GENUS FROM THE UPPER MISSISSIPPIAN.

EDWIN KIRK.[1]

ABSTRACT. A new crinoid genus, *Cymbiocrinus*, is described. The genus ranges from the St. Louis to the high Chester and has a wide geographic range throughout the areas where sediments of this age are found.

CYMBIOCRINUS, new genus.

Genotype.—Cymbiocrinus romingeri, new species.

Crown. Compact and subcylindrical in habit.

Dorsal cup. Shallow, patelliform or basin-shaped, with flattened and invaginated base. Plates typically thick and convex.

IBB. Small, lying within the basal pit but usually extending well beyond the column.

BB. Relatively small, mostly lying within the flattened base, but the distal portions curving upward and clearly visible in lateral view in most species. The *BB* are commonly tumid. *Post B* is truncate, usually supporting a single anal on its distal face. In some specimens *post B* is very large and supports two plates, as will be noted later.

RR. The radials are very large, forming the greater portion of the dorsal cup. The facet extends the full width of the radial. A description of the facet will be found under *C. romingeri.*

IBr. Two in number, short, stout, constricted medially. The union between the brachials is very strong, approaching anchylosis. The earlier species from the St. Louis and "Ste. Genevieve" have a much looser union between the brachials than the later forms. In these earlier species the primibrachs are at times disunited and show offsets either horizontally or ver-

[1] Published with the permission of the Director, Geological Survey, United States Department of the Interior.

tically. The suture between the brachials is clearly shown at all times, however. The suture between the *RR* and *IBr* is linear and gaping.

Arms. The arms are relatively short and stout. The first two *IIBr* are closely united, sometimes showing as a high, completely fused unit. In young specimens and in some rays of many of the adults, especially where weathered, the suture between the brachials is clearly visible. Distad the *Brr* have sloping faces, and for the most part pinnules are borne by succeeding *Brr* alternately to either side. In some species certainly, and probably in all, there is an occasional syzygial pair of brachials taking the place of a single brachial. Syzygial pairs are abundant in the specimens of *C. dactylus* I have examined. They are fairly common in *C. romingeri*. In the later species they seem to be present sparingly, but the preservation of the arms is such as to make observation unsure. The pinnules are long and relatively stout.

Post IR. Typically there is a single plate in the post *IR*. It is doubtful if this is homologous to anal *X*, but we may so denominate it for convenience. In *C. anomalos* and in an undescribed species from Grayson Springs, Ky., the *post B* supports two plates in all specimens seen. In one specimen of *C. romingeri* out of 10 in which the *post IR* is shown, a similar structure obtains. In such cases *post B* is relatively large. It should be noted that all known specimens of *C. anomalos* and the two specimens cited as a new species from Grayson Springs show juvenile characters. It is possible that the structure shown by these specimens in the *post IR* represents an early stage in ontogeny. This possibility is made stronger by one of the specimens from Grayson Springs. In this, one of the tube plates resting on *post B* takes up fully three-fourths the width of *post B*. When there is but a single anal in the *post IR,* the distal surface of *X* at times supports two tube plates and at other times three tube plates. In the latter case the median tube plate is large, flanked on either side by much smaller plates.

Ventral sac. The sac is poorly known. A description of it will be found under *C. romingeri.*

Column. Circular in section, with a pentagonal lumen. The column is unusually slender and incompetent. In only three specimens are fragments of the proximal portions of the column preserved. Whorls of short, slender cirri are borne by the

column. In some species, at least, the cirri appear on nodals within a few millimeters of the cup.

Geologic and geographic distribution.—*Cymbiocrinus* ranges from the St. Louis upward high into the Chester. One species, *C. dactylus* (Hall), is found in the St. Louis of St. Louis, Missouri, and Alton, Illinois. The genus occurs in the "Ste. Genevieve" and Gasper of northern Alabama and the Chester of Kentucky. Poorly preserved specimens of an undescribed species from the O'Hara of Illinois are in the Springer collection.

Relationships.—*Cymbiocrinus* strongly resembles *Graphiocrinus.* Unfortunately we do not know a great deal about *Graphiocrinus,* and we must rely largely on studies of similar, though possibly not congeneric, crinoids from the Mississippian of the United States. These are the types that if not congeneric with *Graphiocrinus* would be assigned to *Scaphiocrinus* of Hall.

There are large numbers of crinoids ranging from the Devonian to the Pennsylvanian that have essentially the same simple structure of the dorsal cup, that is, a dicyclic crinoid with a single anal plate. There is considerable variation in the shape of the cup, but many have a flattened, basin-shaped form with an invaginate base. I do not think it feasible nor desirable to separate these forms generically on the basis of the cups alone. Stratigraphic genera can be made on these cups, but they are of no value biologically, and they will forever be a stumbling block in the path of serious workers of the future.

The family Graphiocrinidae, as of authors, has been used as a catch-all for most of the crinoids with this simple cup structure and with pinnulate arms. The family should be restricted to a compact group of genera, among which there is strong presumptive evidence of phyletic affinities.

Cymbiocrinus differs from *Graphiocrinus,* and indeed from all the described and undescribed genera referable to the Graphiocrinidae, in important details of arm structure. There are two primibrachs as against the single primibrach of *Graphiocrinus.* The arms are relatively more slender in *Cymbiocrinus,* and there is the notable presence of syzygial pairs of brachials, a character never seen in *Graphiocrinus.*

The structures shown by *Cymbiocrinus* refer it to my family Ampelocrinidae. When this family was made I noted (1942, p. 22) an undescribed genus to be referred to it. *Cymbiocrinus* is that genus. The stratigraphic range of *Cymbiocrinus* is also

strong confirmatory evidence in favor of this assignment. *Cymbiocrinus* may readily be distinguished from *Ampelocrinus*. The turbinate cup of *Ampelocrinus*, with the *IBB* showing clearly in side view, is in marked contrast to the basin-shaped cup of *Cymbiocrinus*, with its invaginate base and its *IBB* concealed within the basal pit. The arms in *Cymbiocrinus* are relatively much shorter and stouter than in *Ampelocrinus*.

Species referred to the genus:

Cymbiocrinus anomalos (Wetherby), new combination.

Poteriocrinus anomalos Wetherby 1880, p. 158 (15), Pl. 5, Figs. 6, 6a, b.

"Kaskaskia (Chester) Group, Pulaski County, Kentucky." (Now correlated with the Glen Dean.)

Poteriocrinus anomalos Wetherby. Wachsmuth and Springer 1886, p. 284 (158).

(Note comment as to uncertainty of generic assignment.)

Cymbiocrinus anomalos has structural features considerably at variance with the other known species of the genus. It seems to be rare. Wetherby stated that he had three specimens. There are two specimens in the Springer collection. The label is in Wachsmuth's writing. It is possible that one of the specimens came from Wetherby. It is unlikely that the specimen here figured came from him, as it shows a division of the anterior ray that was not known to Wetherby.

The species is a small one. Wetherby's figures are supposed to be of actual size but may not be. The specimen I figure is almost exactly one-half the size of Wetherby's. The other specimen in the Springer collection is smaller than the one figured. There is a fair possibility that we are dealing with young individuals. There are characters, such as the relatively stout pinnules and the general habit of the arms themselves, that suggest juvenile forms. There is, however, no known larger specimen from this region that can be assigned to the species.

It is in the arm-structure that the species diverges most widely from the other known forms. Wetherby assumed that there was no division of the arm in the anterior ray. As a matter of fact, the seventh primibrach is axillary. In the specimen showing the anterior arm-structure the second primibrach gives a deceptive appearance of being an axillary. Wetherby's figure shows the structure more clearly, however. The distal face of the second primibrach is sharply oblique,

corresponding with other known forms in other genera in which there is a suppressed division. This type of structure has not been described. The primibrachs of the other rays are relatively high and narrow. Each is hourglass-shaped, and there is a widening of the plates at the line of union instead of the customary constriction. The first two *IIBrr* are loosely united, and here again we see a widening at the line of common juncture. The higher *Brr* are slightly constricted medially, and each seems to bear a pinnule. There seem to be no syzygial pairs.

The cup is somewhat flatter than in most species. The most notable character is the great size of *post B*. This is very wide, and its distal point reaches practically to the level of the radial facets.

The *post B* supports two subequal plates that, under the circumstances, can be styled only proximal tube plates. In the specimen figured there are two pairs of tube plates following the first pair in linear series and decreasing in size distad. It is probably this series of plates that Wetherby described as "heavy." The slight evidence I have of the structure of the distal portions of the sac indicates that it is made up in the main of relatively small, thin plates.

Wetherby describes the column as pentagonal in section. Such evidence as I have is inconclusive. In one specimen a badly damaged columnal lies within the basal pit. It does appear to be pentagonal.

Horizon and locality.—Both specimens examined are weathered and could not have come from the freshly excavated material at the railroad tunnel at Sloans Valley. It seems probable that all the specimens were collected elsewhere in the general vicinity and perhaps from a different stratigraphic horizon than the well-known tunnel material.

Cymbiocrinus dactylus (Hall), new combination.

Graphiocrinus dactylus Hall 1860, p. 80.

"St. Louis limestone near St. Louis, Missouri."

Graphiocrinus dactylus Hall. Meek and Worthen 1873, p. 559, Pl. 20, Fig. 9.

Poteriocrinus (*Scytalocrinus*) *dactylus* (Hall). Wachsmuth and Springer 1880, p. 117 (342).

Synonymy.—

Cyathocrinus macadamsi Miller and Gurley 1895, p. 69, Pl. 4, Figs. 31, 32.

There is little doubt that Hall's *Graphiocrinus dactylus* is the form subsequently described by Miller and Gurley as *Cyathocrinus macadamsi*. The specimen figured by Meek and Worthen as *Graphiocrinus dactylus* Hall as from the "St. Louis" of Monroe County, Illinois, may be a distinct species and may not be of St. Louis age. Present opinion is that this horizon may be Ste. Genevieve. Certainly the crinoids I have seen from this horizon and locality do not agree with St. Louis forms.

According to the record, this is a rare form. There is the original specimen described by Hall. Miller and Gurley state that they had three specimens of their *macadamsi* from the St. Louis of Alton, Illinois. As a matter of fact, a search through the collections will probably yield many specimens. There is a crown from St. Louis in the Springer collection in the United States National Museum. In the collections of the United States National Museum there are no less than four dorsal cups and three crowns of the species from the St. Louis of Alton, Illinois. These had been identified as *Decadocrinus? internodius* (Hall).

A few details may be added to the descriptions of Hall and Miller and of Gurley. There are two *IBrr* instead of one as described by Hall. This feature was correctly shown by Miller and Gurley. The first primibach is considerably larger than the second. The first two *IIBrr* are closely united and are proportionally large. Syzygial pairs preponderate in number in the proximal two-thirds of the arms. Commonly, two syzygial pairs immediately succeed the first closely united pair of *IIBrr*. This pair itself appears to be a syzygial pair, though it is not possible definitely to prove that they bear a pinnule. In several specimens the proximal portion of the column is found. The column is slender and made up of clearly defined nodals and internodals. Relatively long cirri are borne in whorls to within a few millimeters of the cup.

Cymbiocrinus grandis Kirk, new species

Plate 1, Figs. 6, 7, 10.

This, the largest known species of *Cymbiocrinus*, is represented in the collections by some nine crowns and five dorsal cups, some of which have portions of the arms attached. The series contains specimens ranging from very young to adult. Unfortunately, especially as regards the crowns, the preservation leaves much to be desired. The specimens as a rule are

crushed, and the better crowns are embedded in a dense, tenacious matrix that cannot be cleared away satisfactorily.

The crown is high and compact. The largest complete crown has a height of 60 millimeters, with a dorsal cup having a height of 5 millimeters and an average diameter of 13 millimeters. Incomplete individuals indicate a possible height of crown of 75 millimeters.

The dorsal cup is depressed bowl-shaped, with flattened base and rounding sides. The basal pit is sharply defined and deep. The largest dorsal cup has a height of 5 millimeters and an average diameter of 15 millimeters. The *IBB* are small and completely hidden within the basal pit. The *BB* are of medium size, the *post B* being the largest and supporting the anal plate on its distal face. The *RR* are large, making up the greater part of the dorsal cup. The anal plate is relatively small and extends but slightly above the level of the *RR*. Where the distal face is well shown, it seems to support but two tube plates.

The *IBrr* are short and heavy. The arms are long and stout. The brachials are lower and more cuneate than in the other known species. Occasional syzygial pairs are found, but they are uncommon. The pinnules are moderately long and slender.

Nothing is known of the ventral sac. As noted above, there seem to be but two tube plates resting on the anal. The median plate is the larger, and in one case the lateral plate is on the left shoulder and in the other on the right shoulder.

The column is circular in section and composed in the proximal portion of alternating nodals and internodals. The nodals bear cirii to within a few millimeters of the cup. The lumen is small and sharply pentagonal.

Horizon and locality.—All the specimens definitely assigned to the species were collected by Charles and Bernhardina Wachsmuth at the railroad tunnel at Sloans Valley, Pulaski County, Kentucky. The horizon is currently identified as the Glen Dean formation of the Chester. There are two specimens doubtfully identified as of this species collected by Lyon in "Grayson County, Kentucky." As Lyon had many specimens labeled "Grayson Springs" and others "Grayson County," it would appear that these specimens did not come from the Grayson Springs locality.

Types.—The holotype, S 4433, and paratypes, S 4433a, b, are in the Springer collection in the United States National Museum.

Relationships.—*C. grandis* may not readily be confused with any described species. The species is the largest known. The dorsal cup is exceptional in that although the plates are convex they are not notably so. The arms are relatively stout, and the brachials are lower and more cuneate than in any described species.

CYMBIOCRINUS LYONI KIRK, new species.

Plate 1, Figs. 11, 12.

Of this species, three specimens are known. One may be assumed to be a mature individual, another is somewhat smaller, and the third is a fairly young specimen.

The crown is high and compact. The crown of the holotype, the largest specimen, has a height of 43 millimeters. The dorsal cup has a height of only 3 millimeters. The dorsal cup is basin-shaped, with flattened and invaginated base.

The dorsal cup has a height of 3 millimeters and an average diameter of 10 millimeters. The *IBB* are small and entirely contained within the basal pit. The basals are of medium size as compared with other species of the genus. They are highly tumid. The distal face of *post B* is truncate and supports a single anal plate. The *RR* are relatively very large, making up the greater part of the cup. The facet is linear and extends the full width of the radial. The anal plate is large, extending slightly above the level of the radials. It supports three tube plates, the central plate large and the lateral plates much smaller.

IBrr, two in number, heavy and slightly constricted at the suture. The suture between the two is clearly shown in all cases, and in one ray there is a lateral offset between the two. The arms are long and slender. The first two secundibrachs are closely united, but the sutures show clearly. The higher brachials have slightly sloping faces, and in most cases, at least, a pinnule is borne by each brachial. Syzygial pairs may be present, but this is not certain.

Nothing is known of the ventral sac other than the proximal row of tube plates. As noted above, three of these rest on the anal. The central tube plate is relatively large, flanked on either side by much smaller plates. The sac apparently was small, incompetent, and made up of a few linear series of small, thin plates.

A few millimeters of the proximal portion of the column is

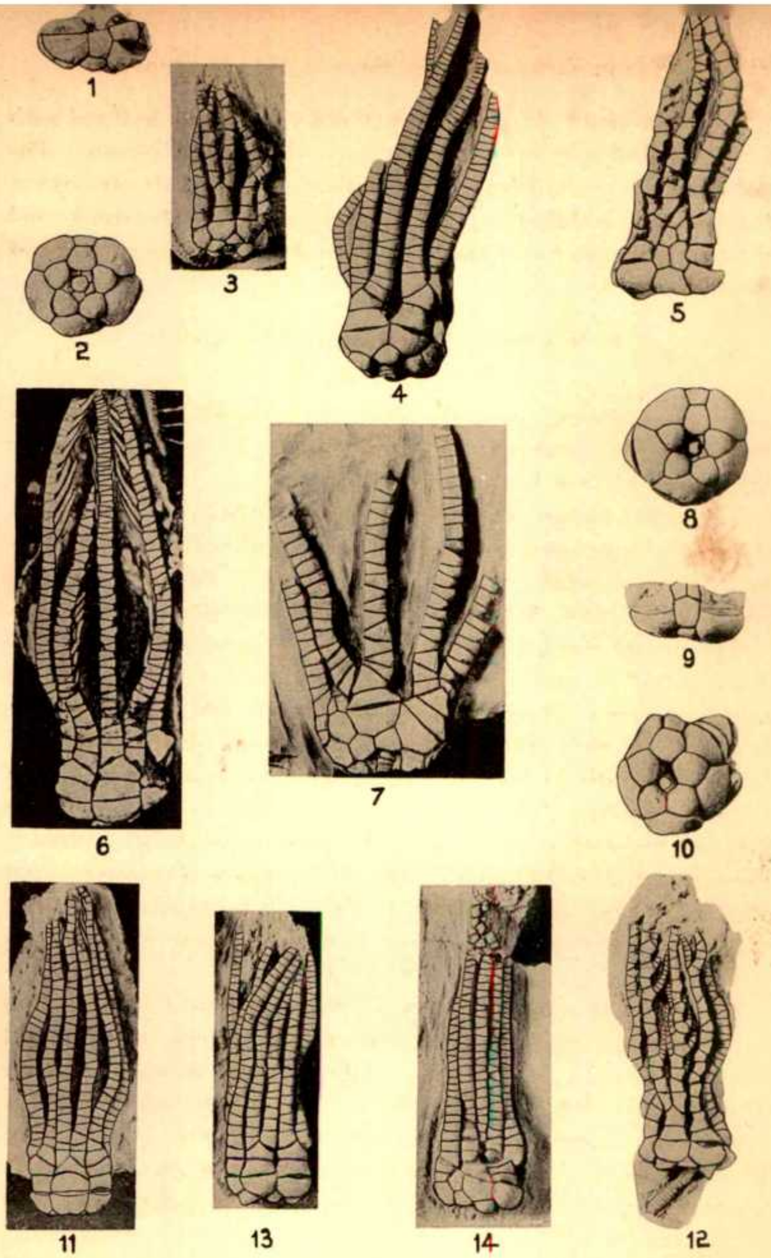

PLATE 1. CYMBIOCRINUS

Figs. 1-4, 8, 9. *Cymbiocrinus romingeri* Kirk, new species: 1, 2, paratype, posterior and basal views of dorsal cup; 3, paratype, young individual; 4, holotype; 8, 9, paratype, basal and posterior views of dorsal cup. All figures x 1½.

Fig. 5. *Cymbiocrinus anomalos* Wetherby, posterior view, x 2.

Figs. 6, 7, 10. *Cymbiocrinus grandis* Kirk, new species: 6, holotype, anterior view; 7, paratype *r posterior* view; 10, paratype, basal view of dorsal cup.

Figs. 11, 12. *Cymbiocrinus lyoni* Kirk, new species; 11, holotype, anterior view; 12, paratype, young individual, x 1½.

Figs. 13, 14. *Cymbiocrinus tumidus* Kirk, new species: 13, paratype, anterior view; 13, holotype, *r posterior* view.

All figures x 1 unless otherwise indicated.

preserved in the smallest specimen. The column is circular in section and unusually slender.

Horizon and locality.—The specimens were collected by Sidney S. Lyon from the upper Chester beds of Grayson Springs, Kentucky. They were probably collected in the 1850's. The horizon has been identified as Glen Dean, but this is far from certain.

Types.—The types, S 4430 and S 4430a, are in the Springer collection in the United States National Museum. They were originally in the Lyon collection, which was purchased by Springer. The species is named for Sidney S. Lyon, pioneer collector and student of the Crinoidea of Kentucky.

Relationships.—*C. lyoni* most nearly resembles *C. tumidus* in general appearance. Its most obvious distinction, as noted under the description of *C. tumidus*, is its less conspicuous basals.

Cymbiocrinus romingeri Kirk, new species.

Plate 1, Figs. 1-4, 8, 9.

Of this species, some 11 crowns and 4 dorsal cups are available for study. Most of the material is in an excellent state of preservation. Although one of the smaller and earlier species of the genus, it has been chosen as genotype because it best shows the characteristic features on which the genus is based.

The species is intermediate in size between the small *C. dactylus* (Hall) of the St. Louis and the general run of species of the higher Chester. The largest crown of *C. romingeri* has a height of 33 millimeters, the dorsal cup having a height of 3 millimeters. The crown is compact. The largest dorsal cup seen has a height of 3 millimeters and a diameter of 10.5 millimeters, somewhat larger than the cup of the holotype. This may be considered as of about maximum size for the species, as the majority of specimens are much smaller.

In young specimens the dorsal cup is rounded and bowl-shaped. In older specimens the breadth increases relative to the height, and the characteristic flattened base develops. The basal pit is sharply defined and deep. The *IBB* are small and entirely contained within the basal pit. The *BB* are relatively small, but their upper portions show clearly in lateral view. The *BB* are very convex in older specimens. *Post B* typically bears a single anal plate on its truncate distal face. In one specimen out of ten in which the posterior *IR* is shown, *post B*

supports two plates. The *RR* are very large, comprising the greater part of the dorsal cup. In one specimen the structure of the articulating face of the radial is well shown. It is a typical muscular articulation. There is a strong, sharply defined, fulcral ridge extending the full width of the radial. The dorsal ligament fossa is narrow but well defined. The ligament pit is large and cuts into and under the fulcral ridge. There is a pair of small, inter-articular ligament fossae and a pair of large, muscular fossae separated by an inter-muscular furrow. The anal plate is large, extending well above the level of the radials, and supports two tube plates.

The first primibach narrows rapidly distad and is considerably larger than the primaxil. Fortunately, in one specimen the primibrachs have separated cleanly in three of the rays, showing the distal faces of the first primibrachs. The structure shown is interesting and apparently unlike anything known in recent crinoids. There is a narrow marginal flattened area. Within this zone and comprising the greater portion of the face, the surface is convex, in one case strikingly so. This convexity reaches its maximum in the area surrounding the ventral groove. Unfortunately, the primaxils are missing, but there must have been a corresponding concavity on its proximal face. In short, we have a concavo-convex union. The marginal flattened zone is traversed by fine, radiating ridges, many of which bifurcate. The convex portion is smooth, with a slightly uneven surface. It is not possible to name this structure in the terms used by workers in modern crinoids, but perhaps pseudo-syzygy would serve. The first two secundibrachs are closely united, but the suture shows clearly. The *Brr* are cuneate. In the proximal portion of the arm in specimens of medium size syzygial pairs of brachials alternate with single brachials. In larger specimens fewer syzygial pairs can be distinguished. This suggests that with advancing age anchylosis and obliteration of the suture transform the pair into a single unit. The pinnules are of medium length and stout.

The ventral sac can be seen in one young individual that is badly weathered and in one adult. Normally, two tube plates are supported by the anal plate. These in turn support a much smaller pair of tube plates. Apparently this median series of heavier plates does not continue far distad. The sac itself extends to about one-half the height of the arms. It seems to have been subcylindrical in shape but being incom-

petent is flattened and distorted in the adult specimen. The sac is made up of a large number of very small, thin plates.

A few millimeters of the proximal portion of the column is preserved in one specimen. There are prominent nodals, separated by as many as five internodals. The nodals carry whorls of cirri even in this portion of the column.

Horizon and locality.—All the specimens come from the so-called "Ste. Genevieve," some 7 miles south of Huntsville, Alabama, near Whitesburg. The holotype was collected by Carl Rominger. The paratypes were collected by Bernhardina and Charles Wachsmuth. It would appear that Rominger was the first to discover this crinoid horizon near Huntsville. The early collections of crinoids by Troost, Worthen, and others were made near the city, chiefly on Monte Sano and from higher stratigraphic horizons.

Types.—The holotype is United States National Museum 110708. The paratypes are S 4434a-c in the Springer collection in the United States National Museum.

Relationships.—*C. romingeri* most nearly resembles *C. dactylus* (Hall), as might be anticipated from their close stratigraphic relationship. *C. romingeri* is a larger form. The arms are relatively longer and stouter, with fewer syzygial pairs. The cup in *C. romingeri* has a more flattened base, and the basals are notably tumid. In *C. dactylus* the basals are convex but not tumid.

CYMBIOCRINUS TUMIDUS KIRK, new species.

Plate 1, Figs. 13, 14.

This species is based on four specimens, three with reasonably complete sets of arms and the fourth a dorsal cup with fragmentary portions of the proximal brachial series.

The species is of medium size, the crown of the largest specimen having a height of 43 millimeters, of which the dorsal cup takes up 4 millimeters. The crown is compact and subcylindrical in habit.

The dorsal cup is composed of thick, tumid plates. In the holotype the cup has a height of 4 millimeters and an average diameter of about 11 millimeters. The cup is basin-shaped, with a flattened invaginate base. The *IBB* are completely contained within the basal pit. The *BB* are of medium size. They are highly convex and show in lateral view as sharply defined bosses. The *RR* are large and distinctly convex. The facet

is linear and extends the full width of the radial. The *post IR* is shown in but one specimen. The anal plate is large and extends well above the level of the *RR*. It seems to have supported three tube plates.

The arms are of medium height and slender in relation to the size of the dorsal cup. The primibrachs are stout, with well-defined sutures between them. There is a marked lateral constriction at the level of the suture. The first two *IIBrr* are closely united, but the sutures show clearly, and in some cases there are offsets of the plates one to the other. The higher *Brr* are almost quadrangular in outline but have slightly sloping faces. Owing to the crowding of the arms and the nature of the matrix, it is not possible to state definitely that syzygial pairs of brachials are present, though it seems probable.

Nothing is known of the ventral sac. The single anal plate shown seems to have borne three tube plates. From the size of the facets it would appear that the tube plate on the left shoulder was the largest. The median tube plate was smaller and the plate on the right shoulder much smaller. This is a considerable deviation from the customary structure of the genus, in which the median plate is usually much the largest. It is probably of little importance, however, and may well be merely an individual variation.

Horizon and locality.—This species is of considerable interest in that the known specimens come from widely separated localities. The holotype is from the well-known horizon correlated with the Glen Dean formation at Sloans Valley, Pulaski County, Kentucky. The other specimens are from the Bangor formation near Huntsville, Alabama. All the specimens were collected by Charles and Bernhardina Wachsmuth. Knowing the old Wachsmuth localities at first hand, I am quite sure the Huntsville locality is at the top of a "mountain" southeast of Huntsville and south of Monte Sano.

Types.—The types are in the Springer collection in the United States National Museum. The holotype is 4431 and the paratype S 4432.

Relationships.—*C. tumidus* and *C. lyoni* resemble one another in their general habit. Both have low, flattened dorsal cups and relatively slender arms. The most obvious distinguishing characteristic of *C. tumidus* is the relatively large, highly tumid basal plates. In *C. lyoni* the basals, though convex, are in nowise so strikingly developed as in *C. tumidus*.

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U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

THE TYPE SECTION OF THE AQUITANIAN.

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ABSTRACT. The Aquitanian Stage of the European Tertiary dates from 1853 and not 1857 (1858). According to the law of priority the type section is in the region of Ajoie, northwest Switzerland and not in the Aquitanian basin near Bordeaux, France. The Aquitanian was assigned to the Oligocene by Mayer in 1858.

THE Aquitanian Stage of the European Tertiary has been the subject of much discussion by many authors particularly as to whether or not it is Miocene or Oligocene, and whether it is younger than the Chattian Stage or equivalent to it, either in whole or in part. The answer to these questions is basically determined by the limits of the type section of the Aquitanian Stage.

Recently the present author had occasion to make an intensive study of the literature dealing with the Aquitanian and noted that all of the many papers[2] examined either assume or state that the type section is in the Aquitanian Basin near Bordeaux, France, and that the Aquitanian Stage was proposed and defined by Mayer in a paper presented in 1857 and published in 1858. No work examined refers to any earlier paper on the Aquitanian than that of Mayer (1858).

Nevertheless, the opening sentences of Mayer's 1858 paper in the section on the Aquitanian Stage indicate an earlier work. These sentences are as follows (freely translated):

> There is no need to justify our division (in the year 1853) of the Aquitanian into two "Stages," the definite division of land and sea in Europe into the two epochs justifies our division. It would be more fitting to criticise our not having recognized this division previously.

Unfortunately Mayer does not list any paper in his bibliography for the year 1853, but his opening sentence leaves no doubt as to its existence.

After an extended search of the literature of that era the present author believes that a paper by Gressly (1853), entitled

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[2] Among the more important papers are: Alimen (1936), Dollfuss (1909), Vaughan (1924, pp. 713-714), and Munier-Chalmas and de Lapparent (1893, pp. 481-482, designation of the type section of the Aquitanian Stage as near Bordeaux, France).

"Nouvelles Données sur les Faunes Tertiares D'Ajoie avec les determinations de M. Mayer," is the paper referred to by Mayer. Other references to the Aquitanian Stage were found in the literature between the years 1853 and 1857, indicating that several contemporary geologists were familiar with Mayer's classification before 1857.

The title of Gressly's paper definitely shows that the age determinations are by Mayer and in the text it is indicated that the classification employed is Mayer's. Further, Gressly (1853, pp. 258-259) says (freely translated):

> After examination of the faunas of subdivision F of the above terrains, the subdivision which in Ajoie is the most important in thickness and extent, Mayer believes it certain that that subdivision corresponds to his Moguntian [Stage], that is to say, to the Tongrian and Rupelian of Dumont. From which one arrives at the following classification, according to Mayer.
>
> The beds A and B would represent the Helvetian with some doubt. The beds C and D would be the Aquitanian. The beds E and F the Moguntian . . .

Thus a definite set of beds are indicated as the Aquitanian. On pages 254-255 a description of the beds involved is given. Subdivision C is a micaceous "molasse" containing fragments of wood and confused leaf imprints and can be easily observed at Papplemont, Courtemautruy and Plainmont-Dessous. Subdivision D is composed of marls and sands, usually unfossiliferous but containing marine fossils at Papplemont and Courgenay where Mayer recognized *Lamna contortidens* Ag., *Anarrhicus*, *Balanus*, *Spondylus*, *Nerita funata* Duj., *Mactra basteroti* May., *Lucina supina* (?), *L. divaricata* Lamk. Thus in Gressly's paper there is given a definite designation of certain beds as Aquitanian, and a description of those beds together with a list of the fossils found. That the beds are largely non-marine, and with the remaining marine beds but poorly fossiliferous, is unfortunate, but it does not remove them from consideration as a possible type section of the Aquitanian.

Further, Gressly's paper (1853, pp. 259-261) has attached to it an addendum by J. Thurmann (of the Swiss Geological "Bureau") saying, in effect, that as they were obliged to use Mayer's classification in the paper, he was presenting therewith Mayer's complete classification in order that the reader might better understand it. This table is as follows:

1. "Pedemontien," Mayer (upper Pliocene)—Represented in Switzerland by?
2. "Placentien" M. (lower Pliocene)—Oeningen? Kapfnach?
3. "Dertonien" M. (upper Miocene)—Upper fresh water "molasse" of the German-Swiss Basin.
4. "Helvetien" M. (middle Miocene)—Marine "molasse" and shell sandstone of the German-Swiss Basin.
5. "Aquitanien" M. (lower Miocene)—Lower fresh water "molasse" of the German-Swiss Basin.
6. "Moguntien" M. (—? nob.) (Tongrian and Rupelian of Dumont)—Upper marine sands of Fontainebleau, Etampes, Mayence, Castel-Gonberto, etc.—Limestone of Ajoie, Bale, Lauffon, Delemont, etc.—"Diablerets" in the Bernese Alps with special fauna.
7. "Parisien" d'O. (upper Eocene)—"Calcaire grossier"; in Switzerland "Diablerets," St-Gall? Schwytz?
8. "Suessonian" d'O. (lower Eocene)—Sands of Soissonais; in Switzerland—?

This table cannot be interpreted as referring only to Switzerland for it refers to French and German sections as well as Swiss and it questions whether or not the "Pedemontien" and "Suessonien" are represented in Switzerland. Nevertheless, under "Aquitanien" he refers only to the deposits in the German-Swiss Basin (the paper by Gressly deals with part of this basin) and does not list any in France. Thus it appears probable that the strata around Bordeaux, France had not yet been correlated with any part of Mayer's classification of the Tertiary.

That the name Aquitanian was used by Mayer for this particular stage is perhaps unfortunate for it immediately implies a connection with the Aquitanian Basin of France to most readers. That Mayer did not consider the deposits of the Aquitanian Basin of France as typical of his Aquitanian Stage is implied in his 1858 paper (p. 190) for he says (freely translated):

> Concerning the synchronism of the four principal formations of the Aquitanian north zone, it remains only to say that this has long been recognized, and needs no further support.

and a few lines farther on,

> In connection with the formations of the Aquitanian south zone, the so-called *Faluns* (that is: Mussel deposits) are in need of special discussion. We have investigated these *Faluns* during an eighteen month stay in the meadows of the South of France, and therefore we can give definite information on their conditions of deposition.

and then after some further statements he proceeds to give a detailed description of the *Faluns* as they occur in the Department of Gironde. It is this area which subsequent workers have considered as the type area of the Aquitanian Stage, yet in his 1858 paper it is clear that Mayer discusses the *Faluns* in great detail because of the confusion existing at that time as to their correlation and not with a view to establishing the *Faluns* as the type of his Aquitanian Stage (see p. 191, where he says: ". . . and here we will investigate the cause for the erroneous classification of Messrs. Delbos and Raulin.").

Thus, in summary of the preceding, we find the following facts:

1. In 1858, Mayer refers to his 1853 division of the Aquitanian (a point overlooked by subsequent workers).
2. An 1853 paper by Gressly on the Tertiary of Ajoie, Switzerland, with determinations by Mayer (according to its title), appears to be the paper referred to by Mayer in 1858.
3. This 1853 paper has as an addendum a table showing Mayer's classification of the Tertiary. In this table the Aquitanian is listed only in the German-Swiss Basin.
4. In the text of this 1853 paper there is a two-fold division of strata which are designated as "the Aquitanian," together with definite locality descriptions and faunal lists.
5. It is evident from the text of Mayer's 1858 paper that he only discussed the *Faluns* of the Aquitanian Basin of France in detail in order to show that the Aquitanian Stage was present there, and distinct from the Helvetian of that area.
6. Munier-Chalmas and de Lapparent did not designate the strata in the Aquitanian Basin as the type section of the Aquitanian Stage until 1893.

In consideration of the preceding six points, it appears to the present author that as long as we abide by the law of priority that the type locality of the Aquitanian Stage is not in the vicinity of Bordeaux, France, but in the vicinity of Papplemont, Courtemautruy, Plainmont-Dessous, and Courgenay, in northwest Switzerland, and includes the strata discussed by Gressly (1853) as beds "C" and "D."

Whether or not these strata in the valley of Ajoie, Switzer-

land are exactly the same age as those near Bordeaux, France has not been investigated. The faunal lists given by Gressly are too small for a critical analysis. In this respect, European geologists should carefully investigate whether or not the Aquitanian of Ajoie is the same as the Chattian of Germany. It appears to the present author very probable that they are equivalent, in which case the name Aquitanian would take precedence over Chattian. If they are not equivalent, their exact relationships should be easily determinable.

With regard as to whether or not the Aquitanian is to be referred to the Oligocene or Miocene; it was referred to the lower Miocene in the 1853 paper (p. 259). At this time the Miocene included much of the strata subsequently referred to the Oligocene (which was not proposed and defined until 1854). However, in Mayer's 1858 paper (p. 171), he says

> the fifth [Ligurian], sixth [Tongrian] and seventh [Aquitanian] stages are Beyrich's Oligocene.

Thus it appears that the Aquitanian as originally described by Mayer should be referred to the Oligocene.

The effect of this 1853 paper on other European Tertiary stage names should also be investigated. The terms "Moguntien," "Helvetien," "Dertonien" (?=Tortonian), "Placentien" (Plaisancian), and "Pedemontien" (?=Astian) are other names that are used for the first time.

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THE GEOLOGICAL SECTION AT THE LIMESTONE MINE, BARBERTON, OHIO.

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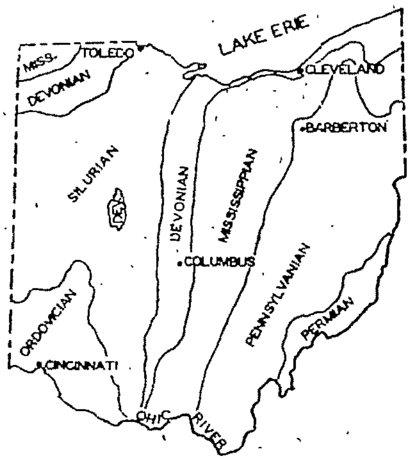
ABSTRACT. For the new limestone mine at Barberton, Ohio, two shafts were sunk to the Devonian limestone 2,197 feet below the surface. The limestone has been opened to an additional depth of 51 feet, modern machinery installed, and the mine designed to supply 1,800,000 tons of limestone annually. These shafts, together with the diamond tests drilled for exploratory purposes, give a combined log of 2,851 feet and thus one of the exceedingly important geological sections of the Lake Erie region. Several disconformities and other indications of interrupted sedimentation are evident in the shales and limestones encountered. There is a suggestion of the Marcellus fauna in a portion of the section but the limestone being mined is the upper part of the Columbus with a typical Onondaga assemblage of fossils.

INTRODUCTION.

BARBERTON is located about six miles southwest of Akron and 40 miles south of Cleveland (See map. Text Fig. 1). It is near the edge of the Pennsylvanian formations on the northwestern margin of the Appalachian geosyncline



Text Fig. 1.

Outline map of Ohio showing the general distribution of Paleozoic systems in the state and location of the town of Barberton.

in the wedge belt of the Devonian and younger beds approaching the northeastern extension of the Cincinnati axis. Wells drilled to the Salina formation have produced brines from this region for many years and the geology has been interpreted

from the logs of such wells, but with the institution of core drilling the knowledge of the section has been much improved. Now there is a shaft down through nearly a half mile of the rocks in question and tons of the rock have been handled by man.

In 1941 the E. J. Longyear Company of Minneapolis started two mine shafts for the Columbia Chemical Division of the Pittsburgh Plate Glass Company at Barberton, Ohio. These were completed, equipment installed, and the mining of limestone was started in August, 1942. The mine is located on Lot 64-T. 1 N.-R. 12 W., a mile west of the south end of Barberton and is connected by electric tram with the main chemical plant about two miles distant.

At the winter meeting of the Minnesota Section of the American Institute of Mining and Metallurgical Engineers on January 12, 1943, Mr. J. Murray Riddell gave an hour's talk on "Shaft Sinking at Barberton, Ohio, With a Description of Mechanical Mucking for Shafts." Mr. Riddell is manager of the Mining Division, E. J. Longyear Company, and was in charge of operations at Barberton. He gave a thorough discussion of the mining operations and the handling of problems met during the excavation and concreting job. Not much time was available for a discussion of the geology nor was it intended to cover that subject during his hour talk. Mr. Lee Armstrong, geologist for the Longyear Company, was on the job at intervals during progress of the work and made several reports to the Company, copies of which are on file in the mine office of the Columbia Chemical Division. These are not for publication although the information in them was available during the study herein reported. Through the courtesy of Mr. Robert D. Longyear arrangements were made with Mr. George A. Morrison, Mine Superintendent, for a personal study of the mine, the rock being removed, the samples from the shaft collected by Mr. Max Tessmer, the underground mine engineer, and the fine set of test cores stored at the mine. The field work for this study was done during the mid-weeks of March, 1943, and materials collected were shipped to the geological laboratory at the University of Minnesota where the study continued.

While at the mine Mr. W. R. Flack, civil engineer for the Columbia Chemical Division, worked with the author at various times and gave much assistance as well as first hand information from direct contact with the job. Mr. Morrison also gave

much of his time, contributed opinions on observations made, and generously allowed the use of samples, records, and equipment—everything in fact that would contribute to the success of the study.

THE MINE.

The mine is designed to recover the greater part of the 48 feet of high calcium rock constituting the upper part of the Columbus limestone and is capable of supplying 1,300,000 tons of rock annually thus easing a shipping situation which called for some 800,000 tons annually down the lakes from Michigan or up from a company quarry in southern Ohio. The elevation at No. 1 shaft is 1,045 feet A. T. and is that of the mine collar.

The shafts to the mine are each eight feet by seventeen feet, start in the Sharon conglomerate and end in the high grade Columbus limestone of Onondaga age, 2,248 feet below, which is the level of the present floor of the mine. To accommodate the machinery, additional excavation was done. At the crusher the bottom of the pit is 2,298 feet and the excavation for the conveyor belt extends down to 2,323 feet below the mine collar or 1,278 feet below sea level. Prior to driving the mine shafts, several test holes were drilled in the immediate vicinity of the mine. Test hole No. 3 is located on the south shore of Lake Dorothy and hole No. 4 across the lake on the north shore—less than a quarter and perhaps a half mile respectively from No. 1 shaft. These test holes were carried down through the limestones and dolomites into the gypsum and salt-bearing beds some five hundred feet below the lowest excavation in the mine. The cores from the limestone were split, half being used for analyses and the other half were available for study as well as the whole cores from the thick shales above.

The shafts exposed completely the Mississippian remnant in northern Ohio, and the drill passed completely through the Devonian. This section cutting over 1,875 feet of Devonian, all but about 130 feet of which was actually exposed, is perhaps the most important and complete Devonian section of the Lake Erie region. Unfortunately, there was no one particularly interested in the stratigraphy on the job during excavation and at this late date it is only possible to retrieve the remnants and piece them together into such restoration as is now possible. This mine is now a very busy place so that

conditions are changing rapidly. Much that is available at present may not be a few months hence. Fortunately the engineers in charge kept an excellent foot by foot record of the excavation, but both shafts are now lined with concrete to the top of the Devonian limestone, thus effectively sealing the rock cut. Many of the hand samples taken at numerous horizons are available and the work is still fresh enough in mind to obtain some information from men who worked on the job. All of this has been utilized and the account herewith seems to be about as accurate as it can now be made.

THE SECTION.

In the section given herewith the measurements are from the shafts as are the descriptions of the strata passed through, although the latter are supplemented by the cores from the test holes (Nos. 3 and 4) of the immediate vicinity. The fossils given in the descriptions of divisions of the section are those from the cores of the same test holes with the exception of a very few actually taken from the excavation. Below the bottom of the mine the measurements and descriptions are based entirely on the cores. These, however, are relatively large and represent a high percentage of core recovery, hence nearly full view of the formations penetrated.

Mine Section.

Elevation at Shaft No. 1 = 1045 feet A.T.

	Thickness	Total
Pleistocene		
Wisconsin		
87. Drift, a sandy clay with gravel and a few boulders	20′–0″	20′–0″
Pennsylvanian		
Sharon conglomerate		
86. Sandstone, buff, cross-bedded, coarse to medium, with bands of quartz pebbles and conglomerate	12′–6″	32′–6″
85. Sandstone, buff to gray, medium to fine	10′–0″	42′–6″
84. Sandstone, gray to buff, medium to fine, interbedded with arenaceous gray shale	13′–4″	55′–10″
83. Sandstone, gray to brown or buff, medium to coarse, with beds of quartz pebble conglomerate	9′–0″	64′–10″
82. Sandstone, gray to buff, coarse	10′–0″	74′–10″
81. Sandstone, gray, coarse to fine	10′–0″	84′–10″

Mine Section—(continued)

	Thickness	Total
Mississippian		
Cuyahoga formation		
80. Sandstone, gray, fine-grained, with gray shale partings	10′–0″	94′–10″
79. Shale, argillaceous, gray, with bands of thin sandy layers	10′–2″	105′–0″
78. Shale, gray, banded, argillaceous	30′–0″	135′–0″
77. Sandstone, gray, fine-grained	10′–0″	145′–0″
76. Sandstone, gray, fine-grained, with interbedded gray shales	30′–0″	175′–0″
75. Shale, gray, argillaceous, with interbedded thin gray sandstones	5′–0″	180′–0″
74. Sandstone, gray, and interbedded gray shale	60′–0″	240′–0″
73. Sandstone, gray to gray-green	10′–0″	250′–0″
72. Shale, gray, argillaceous, banded	5′–0″	255′–0″
71. Shale, gray to gray-green, arenaceous, interbedded with fossiliferous sandstone	25′–0″	280′–0″
70. Shale, gray, banded, with sandstone layers and lenses	25′–0″	305′–0″
69. Shale, gray to gray-green interbedded with layers of gray sandstone. Fossiliferous	10′–0″	315′–0″
68. Shale, gray to gray-green, becoming dark bluish and with occasional thin cross-bedded sandstones	120′–0″	435′–0″
67. Sandstone, gray, fine-grained, with blue-gray shale partings	18′–0″	453′–0″
66. Shale, blue-gray to blue-black	50′–0″	503′–0″
Sunbury shale		
65. Shale, gray to dark gray, more or less brittle	3′–0″	506′–0″
64. Shale, dark gray to gray-black, brittle. In the lower portion *Lingula melie* is common. Fish scales, conodonts (*Prioniodus sp.*, etc.) and *Sporangites* are also common. Sharp contact at the base where the Berea grit is absent	19′–0″	525′–0″
Bedford shale		
63. Sandstone, gray, fine-grained, shaly, oil bearing	1′–8″	526′–8″
62. Shale, gray, soft at top, changing to dark gray with thin bedded fine-grained gray sandstone interbedded	22′–4″	549′–0″
61. Shale, gray to gray-brown	31′–0″	580′–0″
Devonian		
Cleveland shale		
60. Shale, black, slaty, with thin layers of sandstone	3′–0″	583′–0″
59. Shale, black to gray	57′–0″	640′–0″
Chagrin formation		
58. Shale, dark gray, with interbedded sandstones	10′–0″	650′–0″

Mine Section—(continued)

	Thickness	Total
57. Shale, gray, with interbedded gray sandstones	180′–0″	780′–0″
56. Shale, slaty, gray	60′–0″	840′–0″
55. Shale, gray, argillaceous, thick bedded, with thin gray sandstones	35′–0″	875′–0″
54. Shale, gray, slaty	45′–0″	920′–0″
53. Shale, gray, argillaceous, soft	180′–0″	1100′–0″
Huron shale		
52. Shale, gray to chocolate brown; a ⅛-inch seam of gilsonite at the base	130′–0″	1230′–0″
51. Shale, gray to black, banded	118′–0″	1348′–0″
50. Shale, brown to black, with gas	12′–0″	1360′–0″
49. Shale, gray to chocolate brown and black, with gas at base	115′–0″	1475′–0″
48. Shale, chocolate brown to black with bands of gray	139′–0″	1614′–0″
47. Shale, chocolate brown to black with rounded calcareous concretions 10 inches to 2 feet in diameter. Some have calcite veins	6′–0″	1620′–0″
46. Shale, gray to brown and black; a seam of gilsonite at the base	62′–0″	1682′–0″
45. Shale, blue-gray, with crinoid stems and a 2 to 3-inch seam of gilsonite at the base	18′–0″	1700′–0″
44. Shale, gray to brown and black, banded. Gas at base	252′–0″	1952′–0″
43. Shale, gray to brown and black, banded. Scolecodonts and other poorly preserved fossils. Near the base plant fragments appear	100′–0″	2052′–0″
42. Shale, gray to brown, banded	37′–0″	2089′–0″
Hamilton (Olentangy) shale		
41. Shale, blue-gray and gray-brown with pyrite concretions common. A 2-inch layer at the top is filled with pyritized fossils, such as *Tropidoleptus carinatus*, an *Athyris* sp., a large number of *Chonetes* sp., and a few Ostracodes, such as *Hamiltonella* sp.	17′–0″	2106′–0″
40. Shale, blue-gray with *Leiorhynchus multicosta* more or less common	27′–0″	2133′–0″
39. Shale, gray to bluish gray, calcareous, banded with brown or black. *Sporangites* sp. common in the black bands. *Leiorhynchus multicosta* also occurs in these beds. A small quantity of gas given off at several horizons	37′–0″	2170′–0″
38. Shale, blue-black to brown-black, banded, brittle. *Sporangites* sp. and a few conodonts, such as *Lonchodina* sp. found in these shaly beds	20′–0″	2190′–0″

Mine Section—(continued)

	Thickness	Total
87. Shale, brown-black, pyritiferous in the lower part. The following fossils are more or less common near the contact: *Sporangites* several species, Fish teeth, scolecodonts, crinoid stems, *Loxonema* sp., *Tentaculites gracillistriatus*, *Styliolina fissurella*, and numerous conodonts such as: *Angulodus* sp., *Bryantodus* sp., *Hindeodella* sp., *Hindeodelloides* sp., *Ioriodus* sp., *Ligonodina* sp., *Metaprioniodus* sp., *Palmatolepis* sp., *Polygnathus* sp., *Synprioniodina* sp., etc. Very sharp contact at base of black shale and gas encountered at that point	7′–0″	2197′–0″
Delaware limestone (Gas and some oil throughout)		
86. Limestone, gray, partly crystalline, with some cherty nodules. Among the fossils are *Atrypa reticularis*, *Chonetes coronatus* ?, *Spirifer mucronatus* ?, *Spirifer sculptilis* ?, *Spirifer* (*Paraspirifer*) *bownockeri*, the latter occurring at the base	2′–5″	2199′–5″
85. Limestone, gray, partly crystalline, showing several stylolitic bedding planes, a little chert and about a 2-inch shale parting at the base. *Favosites turbinatus*, *Heliophyllum halli*, *Spirifer* sp., *Atrypa reticularis*, *Eunicites* sp., *Lumbriconereites* sp., *Nereidavus* sp., etc., are found in these layers	2′–7″	2202′–0″
Columbus (Onondaga) limestone		
84. Limestone, gray to light gray, with several stylolitic seams or bedding planes conspicuous. A high grade limestone. Some of the common fossils are *Atrypa reticularis*, *Spirifer duodenarius*, and *Stropheodonta inequiradiatus*	2′–5″	2204′–5″
83. Flint or chert, a layer of light gray nodules	0′–4″	2204′–9″
82. Limestone, gray, partly crystalline, showing some good stylolites and containing *Atrypa reticularis*, *Camarotoechia carolina*, *Stropheodonta demissa*, *Stropheodonta hemispherica*, etc.	2′–8″	2207′–0″
81. Flint or chert, gray nodules with some limestone	0′–8″	2207′–8″
80. Limestone, gray, partly crystalline, with *Atrypa reticularis*, *Camarotoechia* sp. *Chonetes hemisphericus*, *Schizophoria propinqua*, *Spirifer duodenarius*, *Spirifer* sp., *Stropheodonta hemispherica*, etc., and showing several seams of stylolite	8′–3″	2210′–11″

Mine Section—(continued)

		Thickness	Total
29.	Limestone, gray, with gray flint or chert nodules at the base	0′–11″	2211′–10″
28.	Limestone, gray, partly crystalline, with *Leptaena rhomboidalis* and *Stropheodonta inequiradiata*	2′–2″	2214′–0″
27.	Limestone, gray, with stylolitic seams and flint nodules	0′–7″	2214′–7″
26.	Limestone, gray, with stylolite and some gray flint in the lower part. Common fossils are *Atrypa reticularis* and *Leptaena rhomboidalis*	1′–6″	2216′–1″
25.	Limestone, gray, with flinty nodules in the lower part	5′–0″	2221′–1″
24.	Limestone, gray, with stylolite seams. *Atrypa reticularis* common. A gas pocket at top	1′–6″	2222′–7″
23.	Limestone, gray, with a few small gray chert nodules, stylolites and several thin black line partings. *Atrypa spinosa* common. A prominent stylolite at the base	4′–7″	2227′–2″
22.	Limestone, gray, partly crystalline, with fine line-like irregular partings near base	4′–0″	2231′–2″
21.	Limestone, gray, partly crystalline, with a small amount of gray chert and several stylolitic seams. The fauna includes *Proetus* sp., *Atrypa reticularis*, and *Spirifer gregarius*, the latter especially abundant	5′–0″	2236′–2″
20.	Limestone, gray to gray-brown showing stylolite. *Spirifer* sp. and other fossil fragments are common	5′–1″	2241′–3″
19.	Limestone, gray, partly crystalline, contains *Atrypa reticularis* and shows a brown shaly parting at the base	1′–10″	2243′–1″
18.	Limestone, gray to gray-brown, with stylolite and brown shale parting near bottom. Common fossils are *Atrypa reticularis*, *Cyrtina hamiltonensis*, *Strophonella ampla* together with various fragments of other fossils. This is the base of the high grade limestone and the bottom of the mine	4′–11″	2248′–0″
17.	Limestone, gray to dark gray, a siliceous limestone with 25% or more SiO_2. Common fossils are *Atrypa reticularis*, *Dalmanites aspectans*, *Stromatoporella* sp., and various corals	3′–3″	2251′–3″
16.	Limestone, siliceous, gray, irregularly banded with brown and showing stylolite. Common fossils are *Atrypa reticularis*, *Cyrtina hamiltonensis*, *Rhipidomella vanuxemi*, *Spirifer*, sp., etc.	2′–3″	2253′–6″

Mine Section—(continued)

	Thickness	Total
15. Limestone, siliceous, gray to dark gray, mottled. These beds contain corals and numerous other fossil fragments	61′–6″	2315′–0″
14. Limestone, siliceous, gray to dark gray, numerous crystal covered fossils and fossil fragments. Corals common	24′–2″	2339′–2″
13. Limestone, siliceous, gray to dark gray, with rough black partings between beds. Corals such as *Diphyphyllum* sp., *Favosites* sp., *Zaphrentis* sp., etc., are numerous	25′–0″	2364′–2″
12. Limestone, very siliceous, dolomitic, gray with light gray chert. Cup corals and other fossils common but not abundant	29′–10″	2394′–0″
11. Limestone, siliceous, dolomitic, gray, with an abundance of light gray chert. Various compound corals common but not abundant, one is probably a *Michelinia* sp.	23′–0″	2417′–0″
Lucas dolomite		
10. Limestone, dolomitic, gray, cherty, with a few corals and brachiopods. Much small fragmentary fossil material shown in the chert	34′–0″	2451′–0″
9. Limestone, dolomitic, gray, sandy. Bottom of very siliceous dolomitic limestone	2′–0″	2453′–0″
Sylvania sandstone		
8. Sandstone, gray to white. A little calcareous material in the lower part. Stylolite at the base and contact sharp	4′–8″	2457′–8″
Silurian		
Bass Island dolomites (20 to 40% $MgCO_3$)		
7. Limestone, dolomitic, gray, with numerous small but conspicuous crystal faces showing. Sharp contact at the base. Fragments of fossils common	10′–0″	2467′–8″
6. Limestone, dolomitic, gray to dark gray, compact. Stylolites common in upper part. No fossils observed	24′–8″	2492′–4″
5. Limestone, dolomitic, dark gray, compact. No fossils found	2′–8″	2495′–0″
4. Limestone, dolomitic, dark gray, compact. No fossils observed. This extends to the bottom of the dolomitic limestone	25′–0″	2520′–0″
3. Dolomite, gray to dark gray, no fossils reported. (Analyses show over 40% $MgCO_3$)	31′–0″	2551′–0″
Salina formation		
2. Gypsum and gypsiferous shales. (Analyses show 50% $CaSO_4$)	200′–0″	2751′–0″
1. Salt with interbedded gray shale and shaly limestone	100′–0″	2851′–0″

KEY HORIZONS.

An examination of this section shows several fairly conspicuous horizons rather easily recognized at once in both the shafts and the cores. These are the base of the Sharon conglomerate, the Bedford-Sunbury contact or horizon of the Berea grit, the contact between the Devonian limestones and the overlying Devonian shales, the top of the Sylvanian sandstone, the top of the gypsum beds and the first salt bed struck in the downward penetration of the drill. Of all these, the one that nobody could miss is the top of the Devonian limestone or the horizon at which the thick Devonian shales abruptly give place to the limestones below. (See Pl. 1, Fig. 3).

The Pennsylvanian, Mississippian, and Upper Devonian formations penetrated may be passed over lightly. They all crop out in the vicinity or along the Cuyahoga River not far distant. Their characteristics are therefore well known or can be checked readily and have been thoroughly covered by others.[1] However, a few features may be pointed out in passing.

Mississippian: The Cuyahoga formation is somewhat thicker than in the Independence region near Cleveland and apparently is composed of the same three members recognized by Cushing and Leverett.[2] The Sunbury shale is present and can be partially separated from the lowest member (Orangeville) of the Cuyahoga formation. Although its thickness is somewhat doubtful, the basal layers of the Sunbury are typical of the formation and carry a fauna quite similar to that found in these beds at the type locality. The contact at the base of the Sunbury is sharp and very marked. The change is from a fine gray sandstone to a fossiliferous gray black shale. The surface of the fine sandstone is uneven. Pyrite nodules, including much sand, occur at the contact and are punched up into the shale as stylolitic pillars showing blackened striated slip sides. The dark shale immediately above the contact carries fish scales, conodonts, *Lingula melie*, *Sporangites* sp., etc., together with some fine grains of sand and finely divided pyrite. The sand below the contact is very fine grained, is mottled dark gray color, and the grains are held together chiefly by clay filling the intergranular spaces. The contact or disconformity just discussed is that commonly occurring in northern Ohio, at the top of the Bedford except that in this case the Berea is absent and the arenaceous beds below it are part of the sandy layers commonly found in the upper part of the

Bedford along the Cuyahoga River and its tributaries as elsewhere in northern Ohio.

Huron—Chagrin-Cleveland shales. Below the Bedford- Sunbury contact there is nearly 1,700 feet of gray to dark gray, brown and black shales that may be separated into formations with difficulty, and it is doubtful whether one is able to draw the boundary lines through them with any degree of accuracy. This results from the ease with which the Chagrin grades into both the Cleveland and the Huron shales.[3] In fact Doctor Prosser regarded the Cleveland as but a western phase of the Chagrin beds and much of the Huron likewise. The condition is further aggravated by a very similar relationship existing between the Cleveland and overlying Bedford shales. Doctor Girty[4] regarded the Bedford as inseparable from the other shales of Upper Devonian age, and the disconformity at the base of the Berea, which in the case of the mine section would be the Bedford-Sunbury contact, as the top of the Devonian. This is the Berea horizon as it is known throughout the state of Ohio and the position of a widespread disconformity.

Of the thick mass of shales occurring below the Berea horizon, the upper 55 feet consisting of gray shales carrying thin beds of fine grained sandstone in the upper part and getting darker gray towards the bottom, are somewhat set off from the beds below. This is doubtless the Bedford shale. It rests on 60 feet of black to dark gray slaty shale representing the Cleveland perhaps with a portion of the Olmsted phase developed.

The division between the Huron and Chagrin is not so easily suggested, but if the thin sandy beds with interbedded gray shales and the more argillaceous gray shales accompanying them be included in the Chagrin, the formation contains about 560 feet of such beds and the Huron shale below it about 990 feet of brown to black shale often banded with gray. It is the Huron that carries the large spherical concretions found in the mine shaft and that are commonly known along the Huron River farther west in the State.

Hamilton (Olentangy) shale. The 112 feet of blue-gray and brown or black shale forming the lower part of the shales in the shafts and in the drill cores, probably belong to the Hamilton. Fossils are not very abundant and the species are few, but such as occur in it are consistent with that assignment. Whether it is the Olentangy shale or some other part of the

Devonian section, is quite a different matter. It is rather firm shale and apparently lacks the argillaceous limestone layers and discoidal concretions characteristic of that formation in the bluffs of the Olentangy River at Delaware and fairly common in the shales along Plum Creek south of Sandusky. An especially disappointing feature of this portion of the section under discussion is the absence of the Centerfield limestone, the New York member of the Hamilton presumably showing up in the Sandusky region as the Prout limestone and across the lake in Ontario as the Hungry Hollow.[5] Even its fauna was not found, although it is probably not safe to conclude that such fauna is entirely absent. It did not seem desirable to break up the cores as much as would be necessary to make a thorough search for such limited faunas in the shale, and that privilege was not requested. From the physical standpoint, however, it may be said that the shales below the probable Centerfield horizon whether they be called Arkona or Olentangy, bear no close resemblance to the shales of similar horizon in southwestern Ontario, the Sandusky region of Ohio, or the type section of the Olentangy in central Ohio. Except that these shales do carry a few fossils, they could readily be included with the Huron shales above, which are markedly similar and often identical in appearance. Even the brown shale at the bottom which marks the contact with the Middle Devonian limestones is not unlike beds in the Huron shale in this same section. Doctor Prosser's account of the samples just above the limestone in the Columbia Chemical Division's Salt Well No. 11 at the Soda-ash plant in Barberton leads one to expect just such rock. In fact his last description is that of a sample of "rather tough black shale with brown streak"[6] probably taken near the contact with the limestone.

The most abundant fossils of this lowest shale are several species of *Sporangites*, *Styliolina fissurella*, *Tentaculites gracillistriatus*, *Leiorhynchus* sp., and various conodonts which were not sufficiently complete in the specimens found for specific identification. Most of this fauna was found in the brown shale band of the lower part and might equally be Marcellus or Hamilton. This great thickness of black, brown and dark gray shales has been regarded as the source rock for oil and gas of certain pools farther to the east in the state. Forty to fifty miles to the north and west of Barberton where these shales crop out local shallow gas wells, supplying sufficient

quantity for lighting and heating a farm house, end in the Huron shale. In fact a recently broken piece of the shale from most any outcrop along the lake west of Cleveland, or still farther west along the Huron River, will give a strong petroleum odor. Distillation experiments have shown this shale to be a valuable potential source of petroleum products. It is not surprising, therefore, that strong flows of gas were encountered at several horizons in the shale and that oil leaks out of the limestone at the contact with the shale. These same Devonian limestones are the producing beds of the oil wells at Petrolia, Ontario, and they are capped by the Huron shale.

Delaware limestone.—Probably the greatest interest in this section centers around the limestones and particularly that one being mined as a high calcium rock. The upper five feet of limestone plus an inch or two of shale is used as the mine roof. These limestone beds carry a fauna which distinctly separates them from the beds below and relates them to the lower part of the Silica shale[7] in northwestern Ohio or to the Sellersburg beds of the Speed quarries in southern Indiana. Doctor Cooper correlates the lower part of the Silica shale with the upper part of the Delaware limestone and the corresponding part of the Marcellus shale.[8] On the suggestion thus made, the limestone forming the mine roof is designated the Delaware limestone although some of the more typical species (*Delthyris consobrina and Martinia maia*) of the Delaware limestone fauna appear to be entirely lacking in it and the physical composition of the beds does not even resemble the formation as it crops out and is quarried at the type section in Delaware, Ohio.

These upper beds of limestone are interrupted by thin argillaceous films, shaly partings, and stylolitic bedding planes that suggest interrupted deposition. The inch or two of shale that forms the basal portion of the Delaware and taken advantage of by the engineer as the parting between roof and mine, is dark gray, pyrite bearing and with blackened upper surface. It incorporates fossils and chunks or nodules of the calcareous mud that are horizontally elongate as if squeezed during the process of lithification. (See Pl. 1, Fig. 4.) The type of accumulation along this thin zone suggests slow if not interrupted sedimentation and seems to mark a break of some importance between the somewhat different faunae. This upper limestone labeled Delaware is not abundantly fossiliferous, but its fauna includes the following species:

Favosites turbinatus Billings
Heliophyllum halli Edwards and Haime
Eunicites sp.
Lumbriconereites sp.
Nereidavus sp.
Atrypa reticularis (Linneaus)
Chonetes coronatus? Conrad
Spirifer (*Paraspirifer*) *bownockeri* Stewart
Spirifer mucronatus? Conrad
Spirifer sculptilus? Hall
Spirifer sp.
Stropheodonta concava Hall

While the identity of some of these forms is probable but not certain, *Spirifer* (*Paraspirifer*) *bownockeri* is unquestionable. The specimen was sliced through by the diamond drill and then halved by the core splitter, but the remnant is still sufficient to identify it. The fragment fits on the brachial valves of this species, shows the side of the prominent acute mesial fold and the six bifurcating costae adjacent. The surface also shows a suggestion of the evenly arranged minute granules characteristic of the species. James Hall undoubtedly had this species from the Hamilton of various localities in Madison County,[9] New York, and may even have had it from the Sellersburg beds of southern Indiana where excellent specimens occur in those beds at the Speed quarries. Hall, however, included it in *Spirifer acuminatus*, a smaller and less advanced form characteristic of the Onondaga. The horizon of the Barberton specimen of *Sp. bownockeri* is definitely fixed at 28½ inches below the top of the limestone in test hole No. 3. The rocks carrying this species and its associated forms appear to belong in the Hamilton group and may be Marcellus in age. The interrupted sedimentation suggested by the bottom part of this thin division is at or very

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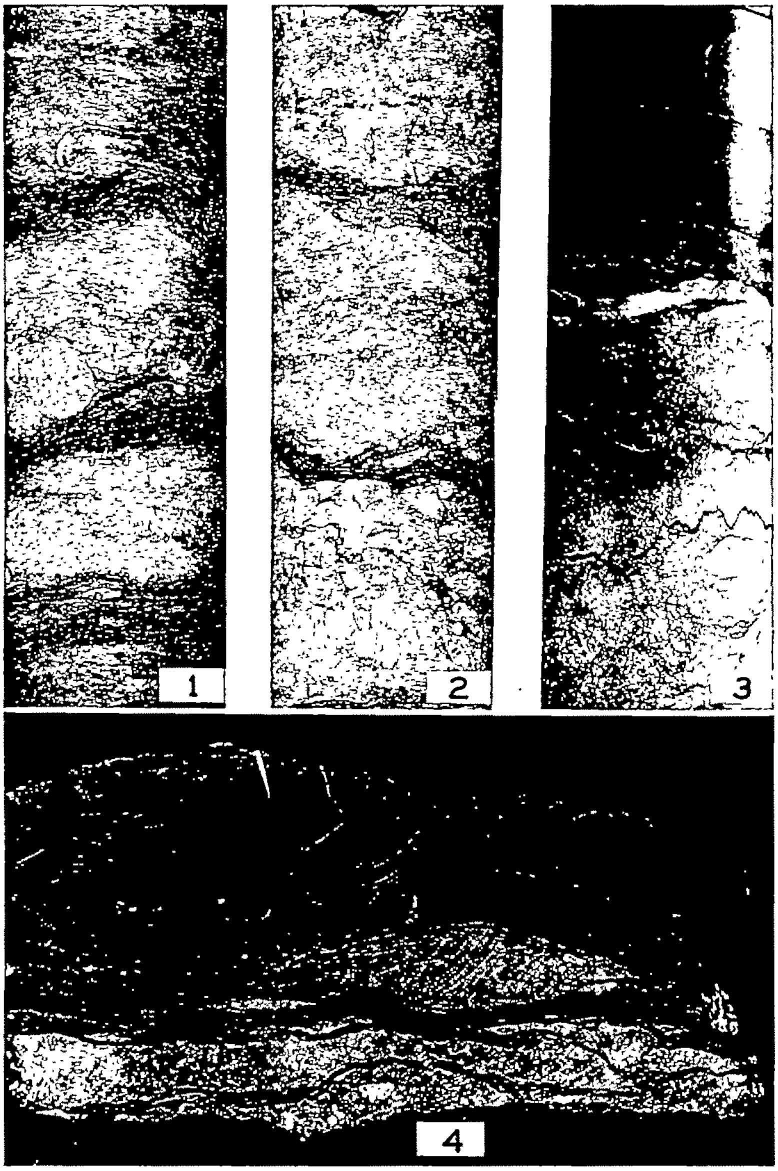
Plate 1 (Two-thirds Natural Size).

Figures 1 and 2. Drill cores from the limestone 852 feet below the surface near St. Thomas, Ontario. The rock in the drill cores below the Columbia Chemical Division Mine shows similar irregular shaly film partings and may be the same horizon.

Fig. 3. Drill core showing Devonian Limestone-Black Shale contact in test hole No. 3 on the south shore of Lake Dorothy, Barberton, Ohio. The limestone also shows stylolite.

Fig. 4. A sawed section of the shaly parting at the base of the Delaware limestone or between mine roof and mine in shaft No. 1.


1
2
3
4

near the contact with the beds carrying a distinctly Onondaga fauna and probably limits definitely the line between Ulsterian and Erian formations.

Regardless of the cherty nodules and shaly partings, this rock ranks as a high calcium limestone averaging about 90 per cent $CaCO_3$ in a foot by foot analysis. Gas and oil escape from these beds and the latter seeps through the roof into the mine at several places in sufficient quantity to produce patches of brown stain.

Columbus (Onondaga) limestone. Beginning with the top of the mine and extending downward through about 220 feet are limestones of various degrees of purity which belong to the Columbus limestone. The 46 feet being mined is the upper part of that limestone and carries a fauna almost identical with that occurring in the limestone at the type section along the Scioto River at Columbus, Ohio. It is a gray to bluish gray partly crystalline limestone in medium to rather thick beds and having horizontal strings or layers of chert nodules at various horizons. These cherty layers are more abundant in the upper part of the mine although they influence the chemical composition of the rock throughout (See Table 1.) Including the

TABLE 1.

Depth below Shale contact	$CaCO_3$	$MgCO_3$	SiO_2	R_2O_3	Ignition loss
1′ to 5′	89.68	2.15	5.82	0.70	0.66
5′ to 10′	84.56	2.81	11.26	0.91	0.57
10′ to 15′	90.15	2.20	5.88	0.70	0.34
15′ to 20′	83.99	2.42	14.45	0.85	0.40
20′ to 25′	85.68	3.18	10.35	0.80	0.00
25′ to 30′	88.71	3.67	6.58	1.09	0.88
30′ to 35′	91.47	3.14	4.42	0.91	0.30
35′ to 40′	88.83	3.54	6.08	1.61	0.00
40′ to 45′	88.35	5.03	4.46	1.45	0.31

Table showing the average composition of the Columbus limestone in the mine. The high silica content of certain zones is due to chert nodules. These separate out in the burning process.

cherty layers the average is about 87 per cent $CaCO_3$ although when these are excluded, the average rises to 94 per cent $CaCO_3$ or better. Below the mine floor the silica content of the limestone shows a marked increase. As in the Delaware, so in the Columbus limestone there are numerous irregular shaly films,

dark wavy partings (See Pl. 1, Figs. 1 and 2), and stylolitic surfaces that suggest interrupted sedimentation and subsequent compaction. The stylolites, some with highly polished and blackened striated sides, have dull black ends and show pillars several inches long. From this generous size nearly all gradations to the incipient stage, scarcely distinguishable from the carbonaceous films and shaly partings may be found. Some of the more conspicuous partings carry argillaceous material with blackened upper surface and shell fragments suggesting the halting sedimentation during the development of under sea disconformity.[10] Conditions of similar purport were prevalent over Minnesota and Wisconsin during the Middle Ordovician,[11] and suggest interesting problems in sedimentation.

The following fauna was collected from the limestone being removed from the mine. Some of this rock may have been quarried out of the pits below the mine floor, but its physical characters indicate that most of it came from the portion constituting the main part of the mine. Most of the species are common, but not abundant and many of them may be seen in the core of Test No. 3 at the mine level.

Stromatoporella sp.
Diphyphyllum archiaci Billings
Diphyphyllum simcoense (Billings)
Favosites emmonsi Rominger
Favosites epidermatus Rominger
Favosites goldfussi d'Orbigny
Favosites hemisphericus (Troost)
Favosites turbinatus (Billings)
Favosites sp.
Syringopora sp.
Zaphrentis corniculum Edwards and Haime
Zaphrentis gigantea Lesueur
Zaphrentis prolifica Billings
Zaphrentis sp.
Arabellites sp.
Lumbriconereites sp.
Crinoid stems
Fenestella sp.
Athyris fultonensis? (Swallow)
Atrypa reticularis (Linnaeus)
Atrypa spinosa Hall
Camarotoechia carolina Hall

Camarotoechia tethys (Billings)
Camarotoechia sp.
Chonetes hemisphericus Hall
Chonetes mucronatus Hall
Delthyris raricosta Conrad
Eunella sp.
Leptaena rhomboidalis (Wilckens)
Leptostrophia perplana (Conrad)
Reticularia fimbriata (Conrad)
Rhipidonella vanuxemi Hall
Schizophoria propinque Hall
Spirifer duodenarius (Hall)
Spirifer gregarius Clapp
Spirifer sp.
Stropheodonta concava Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta inequiradiata Hall
Stropheodonta sp.
Strophonella ampla Hall
Conocardium cuneus (Conrad)
Limoptera pauperata Hall
Pterinea flabellum (Conrad)
Callonema lichas (Hall)
Euomphalus decewi Billings
Loxonema sp.
Dalmanites (*Coronura*) *aspectans* Conrad
Dalmanites sp.
Lichas (*Terataspis*) *grandis?* Hall
Proetus sp.
Fish teeth

Although the Columbus or Onondaga fauna continues below the floor of the mine, the limestone becomes much more siliceous (20 per cent to 30 per cent SiO_2) through the next 116 feet and the importance of the corals in the fauna increases. Finally the corals (***Diphyphyllum, Favosites, Michelinia, Zaphrentis,*** etc.) constitute the most conspicuous fossils in the cherty and silicified material of the drill cores and the lower 53 feet, presumably still Columbus (Onondaga), is a very siliceous (50 per cent to 60 per cent SiO_2) dolomitic limestone.

Lucas dolomite (Upper Monroe formation). Still lower there are 36 feet of very similar siliceous dolomitic limestone in which the fauna is poor and rather scarce, but consists of

corals with occasional fragments of brachiopods. These siliceous rocks just described are the only beds that might be separated in any way from the limestones above that are definitely Columbus. But the relationship of the fauna in the lower 36 feet is still open to question. Doctor Prosser proposed the name Lucas limestone [12] for the upper member of the Monroe formation in northwestern Ohio. In discussing it he said "It includes all the rocks between the top of the Sylvania sandstone and the base of the Columbus limestone or the base of the formation which Doctor Lane in Michigan has named the 'Dundee limestone.'" Doctor Prosser used the name Lucas[13] in the descriptions of the Kenmore and Barberton salt wells and omitted it in the Akron well although in the latter case he did not separate either the Lucas or the Monroe from the Devonian limestones. It may be that he included those names only to show their approximate position above the Sylvania sandstone.

In the Cleveland region Doctor Cushing[14] apparently did separate the Columbus and the Lucas on the basis of chemical composition and applied the latter to the lower 200 feet of dolomitic layers in a 350 foot deposit of limestone and dolomitic beds lying between the base of the Devonian shales and the top of the Sylvania sandstone in the wells of that locality. However, he states that the Lucas dolomite resembles lithologically the Bass Island dolomite. Both of these are described as compact brown dolomitic limestones which would not be a suitable description for much of the rock in the interval under discussion at Barberton. It is quite possible that there are no rocks that should be called Lucas or Upper Monroe in the Barberton section and that the name Columbus limestone or its New York equivalent, Onondaga limestone, should be applied to the rocks down to the Sylvania. But so much of the fauna in the drill cores from the lower 100 to 150 feet here assigned to the Columbus limestone resembles that in the cores taken at 330 to 350 feet in wells near St. Thomas, Ontario (See Pl. 1, Figs. 1 and 2), and assigned to the Monroe, that it seems they and the rocks below must be from that horizon, if not Columbus.

Sylvania sandstone. This formation is thin in the drill core from test hole No. 8 off the north line of the mine property. The Sylvania is sharply separated from the enclosing beds and is the level at which marked change in the type of sedi-

mentation takes place. It is a closely fitted medium to fine grained tightly cemented sandstone. Since deposition, the grains have been partly reconstructed so that quartz crystals with well formed prisms capped by pyramids are evident throughout and the rock is so well cemented that there is much fracture across the grains when it is broken.

The base of the sandstone is slightly calcareous (dolomitic) as if mingled with sediment derived from the beds below, but the contact is sharp and distinctly a disconformity. A small portion of the top shows a tendency to grade into the overlying beds doubtless due to slight reworking of the sand and suggesting that this is but a remnant of a once greater thickness of sandstone. Even two miles distant at the No. 11 Salt Well, Doctor Prosser[15] reports 30 feet of Sylvania while in Cleveland[16] the salt wells show fully 40 feet of the same sand. This so-called Sylvania may be a remnant of the Oriskany sandstone.

SILURIAN.

Bass Island dolomites. Below the Sylvania sandstone the silica content of the dolomitic limestones drops to less than one-twentieth of that of the dolomites above the sandstone. These beds, variously referred to as the Bass Island series, are gray to dark gray compact dolomitic limestones which show sparkling cleavage faces on the fractured surfaces in the upper part where fossil fragments are common but become finer grained, darker and more dolomitic in the middle, then in the lower part pass into beds of dolomite having 40 per cent or more $MgCO_3$. All these limestones and dolomites in this section have been thoroughly analyzed by the Columbia Chemical Division and the results were available during this study.

Salina formation. Gypsum (anhydrite) and gypsiferous shales in which the $CaSO_4$ content makes up more than 50 per cent of the formation in the upper part constitute the youngest Salina beds. These have a total thickness of about 200 feet. The formation then passes downward into beds of rock salt with interbedded shales and shaly dolomites. The cores from this part of the tests are not complete and the greatest depth drilled into the salt series is indicated at 100 feet. This probably carried the tests only into the third salt. There are a number of other salt beds in the region with the total thickness of rock salt exceeding 200 feet and the thickness of all

sediment in the Salina probably reaches 900 to 1,000 feet. Below that the drill would doubtless pass into the Niagara limestone.

SUMMARY.

A vertical rock cut of several thousand feet will expose an important geological section in any region. But one that starts in the Pennsylvanian and ends in the Silurian is superlative especially when that one is largely an open shaft. The Barberton mine section is just that and in a region of much stratigraphic interest besides. Among the important features of this section are the absence of the Berea sandstone, the quantity of gray shale included with and in part replacing the black shales of the Upper Devonian, the absence of the Hamilton limestone, and the shaly character of virtually the whole of the Hamilton group, the near absence of the Delaware limestone and its sharp contact with the shales above, the excellence of the upper part and the high silica content of the balance of the Columbus limestone, and finally the thin but firmly cemented Sylvania sandstone which is almost a quartzite. The most important of all these is probably the 46 feet of limestone being mined. Other horizons are readily identifiable, but its fauna is that of the upper part of the Columbus limestone of central Ohio and furnished the key to the interpretation of the whole section.

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14. Cushing, H. P.: 1931, op. cit., pp. 28 and 31.
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DISCUSSION.

CONWAY ON THE OCEAN: AN APPRECIATION AND A CRITICISM.

Two papers[1] by Prof. E. J. Conway of the Department of Biochemistry, University College, Dublin, relating to the geochemistry of the ocean, have recently appeared. A third member of the series, considering physiological implications, is promised, but since discussion of the geochemical aspects of the matter is evidently completed in the first two papers, it seems desirable to call the attention of American geologists, geochemists, biologists and paleontologists to the series, for Conway's papers are certainly of great importance and deserve wide consideration. Although it is necessary to criticize some of his detailed conclusions at a later stage of the present note, the writer wishes to emphasize that few contributions to biogeochemical theory have appealed as strongly to him as these remarkable works.

The first paper is a preliminary one, considering the geochemical data needed in the second, or principal, contribution. The initial treatment of the composition of rocks mainly follows well-known authorities. A new unit, the geogramme (Gg.) equal to 10^{20} gm. is found convenient and is used throughout. The first important original work is introduced into the consideration of river waters. Here the analyses collected by Clarke in the *Data of Geochemistry* are arranged in groups according to the total salinity, and for each group the median values of the concentrations of the commoner ions are determined and plotted against total salinity. The results indicate rapid rises in carbonate, calcium and magnesium until limiting concentrations are reached, sulphate increases with salinity throughout, while sodium and silicate at first increase, then decrease and later increase again; potassium and chloride appear to increase throughout, but with a greatly diminished rate in the intermediate part of the range. Up to a salinity of 50 p.p.m. the drainage is considered to be from igneous rock, in the intermediate range the drainage is from sedimentary rock, and in the highest range, pollution, salt beds and drainage of semi-arid plains produce an increase in alkali cations and chloride. This presentation of the nature of the chemical variation in inland waters is the clearest known to the writer, and is strongly recommended to the attention of aquatic biologists.

For the purpose of Conway's discussion, the main results obtained

[1] Conway, E. J.: 1942. *Mean geochemical data in relation to oceanic evolution.* Proc. Roy. Irish Acad. Sect. B. 48: 119-159.

————: 1943. *The chemical evolution of the ocean.* Ibid. Sect. B. 48: 161-212.

are the relative proportions of common ions in water draining sedimentary and igneous areas. Conway proceeds to a consideration of the composition of rain water. The treatment is primarily undertaken to ascertain how much of the solutes of river water are not derived from rock. The chlorine delivered from the sea to unpolluted surface waters is considered on the basis of isochlor maps for New England published by Jackson.[2] A theory is advanced, analysing these maps in terms of virtual diffusion, but it is shown that to obtain a good fit two independent diffusion processes must be postulated, so that at any distance x from the coast, c the concentration of chloride is given by:

$$c = 5.7\ e^{-0.059x} + 0.55\ e^{-0.039x}$$

Integrating between $x = 0$ and $x = \infty$, and multiplying by the length of coast line of the earth and the total rainfall, the total cyclical chloride deposited in unit time is obtained as 0.69 Gg. per million years. This type of argument is probably adequate to discover the order of magnitude of the parameter required, but it is uncertain if the mathematical analysis indicates anything as to the nature of the mechanism involved; no claim that the dual diffusion system is other than a mathematical fiction would in fact appear to be made. It is found that, allowing for chloride derived from salt beds by human activity, and for the supposed amount liberated in the denudation of rocks, 35 per cent of the annual discharge is unaccounted for. It is supposed that the deficiency is primarily due to an underestimation of the chloride liberated from sediments, notably from salt beds. It seems more probable that part of the deficit is due to the limited data used in obtaining a value for the chloride precipitated in rain. To have accounted for 44 per cent of the estimated chloride of rivers by an empirical mathematical method applied to a short length of coast line, seems to the writer a remarkable achievement. Since the order of magnitude is correct, further work using more extensive data should provide a more accurate value. Meanwhile Conway is doubtless right in assuming that 95 per cent of the chloride in water from igneous rocks, and all the chloride in water from sedimentary rocks, is cyclical. No bicarbonate is believed to be present in rain water. The sulphate content of rain, however, introduces a serious complication, because in the interior of continents, even far from sources of contamination, the sulphate usually greatly exceeds the chloride. Since combustion of fuel is quite inadequate to explain this, and since the amount in river water implies the presence of far more sulphate in the ocean and the sediments than is actually found, it is certain that

[2] Jackson, D. D.: 1905. U. S. Geological Survey Water Supply Paper no. 144.

this sulphate is cyclical and of marine origin. In a final section appended to the paper, Conway suggests that it is formed from H_2S, which gas, generated from sulphates in marine muds, might diffuse into the atmosphere. It seems certain that the sulphate of rain must originally be present in a more volatile form than the chloride. For the purpose of correction of river water for cyclical substances 89 per cent of the sulphate, transported independently of chloride, is considered to be of marine origin. The bases of sea water are distributed in their oceanic proportions with respect to chloride, and the sulphate is balanced by bases in their proportions in sedimentary rocks. A mean igneous and mean sedimentary river water, free of cyclical salts, are thus obtained by subtraction.

The final problem of the first paper consists in determining the relative losses of different substances from parent rock in one cycle of erosion. Data obtained from eight analyses by G. P. Merrill[3] are first considered, leading to the belief that in the formation of the mean weathering product 60 per cent Ca, 51 per cent Mg, 85 per cent K, 47 per cent Na and 84 per cent P are leached from the parent material. These figures are known to be very rough, though it seems possible that further data could have been obtained from more modern sources. An indirect method of computation, of considerable interest, is therefore adopted. The analyses of thirty-nine shales given by F. W. Clarke[4] are considered and the ratios of the amounts of Na, K, Mg, Ca, P, Al, Si and Fe that are present, to the amounts expected from the composition of the average igneous rock, are computed. A logarithmic histogram is then constructed showing the frequency of the ratios. The modal ratios for K, Si, Al, and Fe represent no loss. The ratios for the other elements represent losses in every case. Moreover, the ratios for the first four elements are grouped normally about the mode, while for the other four elements there is much scatter and an indication of multimodal distribution. For sodium three modes are supposed to be present, corresponding to three cycles of erosion, at each of which 44 per cent of the sodium is lost, in extraordinary agreement with the result derived from Merrill's eight analyses. Taking the median values for P, Ca and Mg for each modal group of sodium contents (0.40-0.79 per cent, 1.00-1.59 per cent and 2.00-3.10 per cent Na), the losses per cycle for these elements are found to be P 39 per cent, Ca 67 per cent, Mg 20 per cent. The agreement for the first two elements is again remarkable, but for magnesium is poor. The scatter in Merrill's analyses for magnesium loss is so great that no great agreement need be expected. In spite of the elegance of these results, some criticism is necessary. The

[3] *Treatise on Rocks, Rock Weathering and Soils.* 1897.
[4] U. S. Geological Survey. Bull. 228. 1904.

multimodality of the sodium histogram is not clearly established, though this is not necessary to the argument if relative rates rather than quantity per cycle are all that are required. A more serious objection lies in the fact that if a regular pattern of the kind postulated exists, it is obvious that late shales should contain less sodium than do early shales. This is not borne out by the composites analysed by Clarke, for the Mesozoic composite contained 1.80 per cent Na_2O, while the Palaeozoic composite contained 1.01 per cent Na_2O. It is, however, possible that since most of geological time is pre-Cambrian, no great difference can be expected in two groups of sediments dating from after the opening of the Palaeozoic. It may be pointed out that Cambrian material is over-emphasized in Clarke's series, leading to a probable reduction in the height of the supposed mode representing the third cycle in Conway's graph.

Another difficulty concerns phosphorus. This element is said to behave in a way "somewhat resembling sodium in percentage losses and in relative reappearance in the shales." It is, however, obvious that the mechanism of this behaviour is quite different in the two cases, and if the resemblances are real, it is because phosphorus may be deflected into the inaccessible sediments of the permanent oceanic basins,[5] while sodium remains in the ocean. Unfortunately comparison of Clarke's and Vogt's[6] tables for the mean composition of primary rock shows an almost twofold discrepancy in the case of phosphorus. If Vogt's figure is preferable, as Goldschmidt[7] believes, then phosphorus will resemble the more or less invariant elements Al, Si, Fe and K. This, however, will introduce uncertainty into the interpretation of the multimodality of the other histograms. Certain difficulties must therefore be overcome before Conway's method of treating the geochemistry of cycles of erosion can be accepted. As in other aspects of sedimentary geochemistry, very many more analyses are now needed. One of the great values of theoretical treatment of the kind that Conway has attempted, is to show what lines of laboratory study are likely to be profitable.

Turning to his main problem, the changes in ionic concentration of the ocean, Conway points out, at the beginning of the second paper, that the variation in the two most important constituents of sea water, namely water and chlorine, must at present remain hypothetical. For both substances two extreme hypotheses can be entertained, namely that the substance was originally present at the surface of the earth, or that it has been added gradually from volcanic sources. Four extreme hypotheses must therefore be considered:

[5] Kuenen, Ph. H.: 1941. Amer. Jour. Sci. 239: 161-190.
[6] Vogt, J. H. L.: 1931. Norske Vid. Selsk. Skr. Oslo. Mat.-Natur. Kl.
[7] Goldschmidt, V. M.: 1937. Norske Vid. Selsk. Skr. Oslo. Mat.-Natur. Kl.

1. That the water is an initial atmospheric condensation, to which chloride has been added (*constant volume-volcanic chloride*).
2. That both water and chloride are the result of initial condensation (*constant volume-constant chloride*).
3. That both components have appeared gradually (*volcanic ocean-volcanic chloride*).
4. That the chloride was present as metallic chloride at the earth's surface and that volcanic water has been added (*volcanic ocean-constant chloride*).

The last hypothesis is considered the most unlikely[8] by Conway, and is little considered. It is, however, shown that after the pre-Cambrian, the evolution of the ocean will follow a course of essentially the same nature on this and on the second hypothesis. The third hypothesis leads to results intermediate between those of the first and second. To the present writer it seems the most likely of the four limiting possibilities, though it is doubtful if the extreme form of any of the postulates will ultimately prove acceptable. It is, therefore, rather unfortunate that the detailed analysis is confined to the first two hypotheses.

Having stated these postulates, Conway proceeds to construct a time scale. In his scale, the time intervals are measured in terms of thickness of sediments deposited, the sum of the maximum thicknesses (s), supposedly proportional to mean thicknesses, from the beginning of the Archaean ($s=0$) to the present time ($s=1$), being taken as unity. Actually the pre-Cambrian thicknesses are determined by extrapolation. The sum of thicknesses backward from today plotted against radioactive time-determinations gives a straight line on double logarithmic paper. When this line is extrapolated to 1750×10^6 years, a value of 1,180,000 feet for the sum of the maximum thicknesses is obtained. Actually it was found convenient to take 1,050,000 feet, from a free-hand curvilinear plot on ordinary graph paper, this corresponding to an initial rate of sedimentation of 0.6 feet per 1,000 years. This rate is less than at any other time in geological history, presumably because initially there were only resistant primary rocks as source material. Such a conclusion raises obvious objections, but the very earliest stages may be of little quantitative importance, and the known Archaean sediments, with their thick varves, may be highly unrepresentative.

The next problem considered is that of deducing simple equations relating the sodium delivered from a land surface in which the easily soluble sediments low in sodium are increasing in area, while the more resistant igneous rocks rich in sodium are decreasing.

[8] Compare, however, White: 1942. Amer. Jour. Sci. 240: 714-724. A superficial deposit of dry metallic chloride might be the explanation of the dust of high albedo in the atmosphere of Venus.

Two fundamental equations are derived, both assuming continuous variation, and so smoothing orogenic events. The values of the constants in the equations are derived from the first paper. The first equation represents the relation of concentration of sodium in the sea (c_0) to concentration in the weathering rock (c_r) at any stage s.

$$c_0 = \frac{1.10 \int_s^0 c_r ds}{\int_{1.0}^0 c_r ds}$$

The second equation relates the variation of c_r the changing composition of the eroded rock, to s.

$$c_r = \frac{(1.6-0.8s)(1-e^{-1.38s})+0.57e^{-1.38s}}{1-0.8\,e^{-1.38s}}$$

The second equation is evaluated and integration of the first is then performed graphically. A series of values for the total sodium in the ocean at any value of s can thus be obtained. The derivation of the equation appears reasonable, provided no great detail over short periods of time is required.

Before proceeding it is necessary to examine the problem of the bicarbonate in the sea. Here again two hypotheses of origin must be considered, that the CO_2 was initially present in the atmosphere, or that it was added gradually from volcanoes. The possible contribution of an extraterrestrial source of carbon from meteorites is shown to be quantitatively negligible. If the CO_2 of the sediments and ocean was originally atmospheric, initially about 10 atmospheres must have been present. Assuming a continuous general rate of carbonate production, 0.6 atmosphere would attend the birth of the mammals in the Jurassic. It is argued that this is a quite impossible quantity in the atmosphere breathed by any animal organized like a modern mammal.

In part following Poole,[9] it is suggested that the great excess of fossil organic carbon in the sediments over the free and fossil oxygen is due to the combustion of volcanic methane which would increase the carbon and reduce the oxygen in the balance for the whole biosphere. Volcanic hydrogen and CO may also be involved. The discussion of this phase of the problem is admirable and should do much to clarify thought on the history of the atmosphere.

Conway now proceeds to a detailed consideration of the evolution of an ocean of constant volume, receiving its anions from volcanic sources at a constant rate. The sodium content is determined from

[9] Poole, J. H. J.: 1941. Sc. Proc. Roy. Dublin Soc. 22: 345-365.

the calculations already discussed, and the volume being postulated as identical with the modern ocean, the concentration of sodium can now be plotted. Having indicated the progressive rise of sodium, the history of potassium is next considered. It is well known that the potassium of the ocean does not accumulate but is largely removed in argillaceous sediments. Conway dismisses base exchange adsorption on sedimenting clays as a quantitatively inadequate mechanism, and supposes that initially potassium accumulated like sodium. He postulates the cell to have originated somewhat after the middle of the pre-Cambrian; the consequent rise of decomposition on the sea-bottom led to a biogeochemical removal of potassium as glauconite. The excess chloride anions left in solution are considered to have an important role in regulating the magnesium and calcium balance.

The magnesium, calcium and sulphate contents of the ocean are then considered, and are believed to be closely interrelated, the alkaline earths being in apparent equilibrium with their carbonates, and calcium with its sulphate, in sediments. The detailed changes in concentration depend on the changes in the difference between alkalies and halides, and this difference depends in turn on the removal of potassium from the sediments. A rather elaborate treatment indicates that on the basis of *constant volume* and *volcanic chloride,* the concentrations of magnesium and calcium rose at first, then fell to a minimum when potassium fixation began and rose again rapidly about the beginning of the Cambrian. On the basis of *constant volume and chloride,* the initial excess chloride is supposed to have been largely balanced by calcium. The calcium is then believed to have fallen to a minimum when potassium was maximal, and then to have risen again, as on the basis of the first hypothesis. The maxima and minima in magnesium occur at the same time on the basis of the second hypothesis as on the first. On the third hypothesis an intermediate series of changes may be expected. Little change in oceanic pH will occur throughout geological time.

Whatever hypothesis is considered, there is no possibility of wide divergence in relative composition between the Ordovician ocean and that of today. All hypotheses relating the cation content of vertebrate body fluids to such changes are therefore doomed to failure.

It will be clear from the condensed summary that has been given above, that the detailed changes in all cations save sodium are considered to be interdependent and to be controlled primarily by the removal of potassium. This general statement is of great importance, and to the present writer its acceptance appears inevitable. In view of the paramount significance of removal of potassium, Conway's postulate that the process started with the biogeochemical synthesis of glauconite in the middle pre-Cambrian must be sub-

jected to the closest scrutiny. The validity of the quantitative details of the changes in magnesium and calcium depends entirely on the correctness of such an hypothesis. Unfortunately in this phase of his investigations, Conway has relied too much on the older geochemical literature, and his conclusions are suspect on all counts.

(1) The postulate that biogeochemical processes began in the middle pre-Cambrian is arbitrary and unsupported by any objective evidence. Actually the meagre available indications suggest that such processes, producing both organic carbon and sulphide, had already begun in the Archaean.[10]

(2) The postulate that the potassium in shales is removed from the ocean biogeochemically as glauconite would imply that 20-30 per cent of the average shale consists of that mineral. Actually the most important potassium-bearing secondary minerals of unmetamorphosed shales are the hydrous micas of moderate potassium content known as illites.[11] These may have some formal relationship to glauconite, but there is no evidence that their genesis is biogeochemical.

(3) The meagre series of available analyses[12] of Archaean argillaceous sediments relatively free from undecomposed rock fragments are consistent with the uniformitarian view that potassium removal started as soon as an ocean developed. It appears, therefore, that the most probable hypothesis is that potassium has always been removed from the ocean at approximately the present rate. On the *constant volume-volcanic halogen* hypothesis, this implies a rise in calcium in the middle pre-Cambrian and a relative constant concentration thereafter; on the *constant volume-constant halogen* hypothesis, calcium would decline throughout geological time. On an intermediate hypothesis as to chlorine, with some volcanic water, little if any change in calcium concentration need have occurred. Conway's graphs showing the course of calcium change, assuming constant removal of potassium, though introduced merely to be rejected, may be the most interesting result of his studies. They naturally indicate no such increase of calcium at the opening of the fossil record, as would occur if potassium loss did not start until the middle pre-Cambrian.

To settle this and cognate problems, very many more analyses of ancient argillaceous sediments are needed, as well as a far more intense study of the colloid mineralogy of modern pelogenesis. It is worth noting that not only potassium, but rubidium, caesium and lithium are almost quantitatively removed from the ocean. The first

[10] Eskola, P.: 1932. Ann. Acad. Sci. Fenn. 36 (A): 1-70.
Pettijohn, F. J.: 1943. Bull. Geol. Soc. Amer. 54: 925-972.

[11] Grim, R. E.: 1942. J. Geol. 50: 255-275.

[12] Eskola, P.: l.c., particularly analysis no. 7.

two elements presumably occur in an interstratal position, like potassium, while lithium probably enters octohedral positions, in the secondary clay minerals.[18] Future studies should include analyses of the rarer as well as the commoner alkalis and alkaline earths. Determinations of selenium and of boron might also prove instructive.

The importance of Conway's contributions lies in his application of a reasonable deductive method to marine geochemistry, in his emphasis on the controlling effect of removal of potassium, and in disposing once and for all of the hypothesis that the body fluids of homoiosmotic animals represent samples of sea water collected at the time when their body walls became impermeable to electrolytes. The weakness of Conway's results lies in the arbitrary assumptions introduced in treating the loss of potassium. If the testing of his detailed conclusions leads to a renewed chemical study of the development of ancient marine sediments, his whole contribution will initiate a great advance in our knowledge of a difficult but fascinating subject of great importance to the geochemist and to the biologist.

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[18] Hendricks, S. B., and Ross, C. S.: 1942. Amer. Mineral. 26: 683-708.

DISCUSSION.

THE WALLOWA BATHOLITH

In the October (1943) issue of The American Journal of Science, K. B. Krauskopf published a paper[1] on the Wallowa Batholith, and I was gratified to note his consideration of an attractive hypothesis of origin. A paragraph on page 627 contains this statement:

"The ultimate origin of the quartz-diorite is an elusive question to which data at present avalable cannot provide an answer. Perhaps the bulk of the material rose as a silicate melt from far below, as batholiths are traditionally supposed to do; no conclusive evidence can be cited against such a view. Since the borders of the intrusive show good evidence for widespread granitization, a more attractive hypothesis would be formation of the quartz-diorite by metasomatic alteration of metamorphic rock accompanied by some movement of the mass as a whole—essentially Goodspeed's idea, modified to eliminate its chief difficulties."

Krauskopf evidently believes that the "chief difficulties" are those relating to the formation of all the granodioritic rock by static metasomatism, and implies that the concept that metasomatism may have been accompanied by plastic flow is new. But in one of my previous papers[2] which was not quoted by Krauskopf, I suggested flowage of metamorphosed material. The second paragraph of this article on page 399 is as follows:

"There are several areas in the southeastern portion of the Wallowa Mountains of Oregon where by reason of steep glacial valleys or extensive mine workings there are excellent exposures of various kinds of metamorphic and plutonic rocks. Many of these field occurrences would suggest to the casual observer only the usual interpretation for the emplacement of the granodioritic masses, namely, injection accompanied by piecemeal stoping, with a minor amount of assimilation. However, critical field data obtained by the writer during the past ten years and substantiated by the petrographic study of several thousand thin sections have forced him to abandon the simple magmatic hypothesis for a more complex one of metasomatic replacement. By this interpretation, most of the granodioritic masses in the vicinity of Cornucopia are considered to be the end products of progressive metamorphism. However, there are a few occurrences which suggest that, locally, the newly formed products of metamorphism were subjected to a mass movement of plastic flow. Such newly formed magmatic material might be termed *neomagma* in contrast to *hypomagmas* of presumably deep-seated sources. In this region, numerous Tertiary basaltic dikes present excellent evidence of magmatic injection, and could, therefore, be termed orthomagmatic in origin."

[1] Krauskopf, K. B.: 1943. The Wallowa Batholith. Amer. Jour. Science, Vol. 241, pp. 607–628.

[2] Goodspeed, G. E.: 1939. Pre-Tertiary metasomatic processes in the southeastern portion of the Wallowa mountains of Oregon. Proc. Sixth Pacific Science Congress, pp. 399–422.

On page 417 of the same paper is this paragraph:

"At a very few localities in this region there are drawn-out inclusions and schliern where the granodiorite intimately mixed with recrystallized hornfels has the appearance of complex flowage. The actual plastic flow of such a magma might be considered to be a neomagma, and of metamorphic rather than of orthomagmatic origin. In some regions the amount of plastic flow of granite material may be large, but in the vicinity of Cornucopia the evidence to date indicates that it was small. However, in this region there is much cogent evidence to the effect that metasomatic replacement played a most important role in the emplacement of large granodioritic masses."

The concluding paragraph on page 421 is:

"In this part of the Wallowa Mountains, such evidence as the contact relations, and the presence of undisturbed relics of inclusions, suggest that granitization took place passively and without mass movement. It might be expected that in some regions recently granitized material might be subjected to plastic flow and hence become a neomagma. Granite and granodiorite formed as a result of the injection of neomagma would of course show those structures which are characteristic of flowage."

Having recently had the opportunity to see some of the relatively large laccoliths of the Little Belt mountains of central Montana, I was impressed with evidence of orthomagmatic injection of these syenitic and granitic bodies in contrast to the plutonic masses in the southeastern portion of the Wallowa mountains of Oregon. However, many of these Montana intrusive bodies are by no means simple, and I should hesitate to advance simplicity of composition and texture (as Krauskopf does) as criteria against metasomatic origin.

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SCIENTIFIC INTELLIGENCE

Physics.

Applied Nuclear Physics; by ERNEST POLLARD and WILLIAM L. DAVIDSON, JR. Pp. vii, 249; illustrated. New York, 1942 (John Wiley & Sons, Inc., $3.00).—This book as its title indicates is concerned principally with those nuclear phenomena and techniques which have applications outside of research in nuclear physics, and in the words of the authors is intended to reach "the growing army of chemists, biologists, physicians, and engineers, who, though not necessarily versed in the language of physics, are using the products of nuclear physics to further their ends in their own spheres." That nuclear theory which is discussed is qualitative and is presented simply to clarify the phenomena themselves, a viewpoint which is entirely consistent with the purpose of the book.

It is erroneous to neglect the value of the book to the physicist, for within its pages are compact and authoritative summaries of material otherwise only available in periodicals. There are convenient lists of key references (including short comments on the references) at the end of each chapter, and appendices containing tables of stable nuclei, common radioelements, absorption formulas and numerical values, as well as thirteen problems. All of these latter features should make the book valuable for an undergraduate course in nuclear physics, or for a reference text in a modern physics course, or a course in radiology, to mention only a few possibilities for its use in teaching.

A few introductory chapters are followed by extensive sections on nuclear instruments, detectors and accelerators, these latter being kept general enough to include the possibility of any rapid development in techniques. Those instruments which are described in greater detail are just the instruments which have proved their extreme usefulness throughout a decade of rapid development in nuclear physics, a guarantee against their becoming extinct in the immediate future.

The chapters concerned with nuclear phenomena are well organized with handy tables for reference, and, as in the chapters on instruments, are profusely illustrated with experimental curves and diagrams of set-ups. Sections on tracer experiments, biological effects of nuclear radiations, isotope separation, etc., make the book an excellent liaison agent between physics and its neighboring sciences.

"Applied Nuclear Physics" is a unique addition to the literature of physics, for it is the first authoritative book to make generally available a large body of knowledge which hitherto has been available only to specialists and research workers. The continually

widening applicability of nuclear phenomena and techniques accentuates the importance of this book. J. G. BECKERLEY.

CHEMISTRY.

The Theory and Practice of Semimicro Qualitative Analysis; by G. B. Heisig. Pp. xiii, 381; 15 figs., 28 tables. Philadelphia, 1943 (W. B. Saunders Company, $2 50).—This text is "designed for the use of students who have had a thorough course in general inorganic chemistry." The arrangement of the content is such that the book is readily adaptable to either a two semester or a one semester course.

The first six chapters of the theoretical part review and amplify those principles of general chemistry of direct importance to qualitative analysis. The treatment of oxidation-reduction seems rather brief, and is a part of a chapter which includes also complex ions and the colloidal condition. This chapter follows one on the Application of the Law of Mass Action to Saturated Solutions and precedes a chapter on Hydrogen Sulfide as a Precipitating Agent and the Solution of Sulfides, thereby breaking the continuity of the development of solution theory. Otherwise the discussion of theoretical principles is well organized. In his applications of the law of mass action in these chapters the author uses only the ionic concentrations; then in the seventh and final chapter of this section he takes up the use of the activity concept in detail. Thus those who like to defer the application of this concept will probably find that this treatment fits well with their procedure. Each chapter ends with an extensive set of well-chosen questions and problems.

In the experimental part standard procedures are given for the separation and identification of twenty-four cations and an equal number of anions. The pressure-bulb technique is used for filtrations. Although directions are given for centrifuging and subsequent treatment, the student who employs this method is likely to encounter difficulty because of lack of details. In the descriptive sections, the preliminary experiments, and questions at the end of each analytical group there is ample material for the development and extension of the student's knowledge about the properties of ions. HAROLD G. DIETRICH.

GEOLOGY.

African Handbooks: *2. The Mineral Resources of Africa*; by A. WILLIAMS POSTEL. Pp. v, 105; 19 figs. Philadelphia, 1943 (University of Pennsylvania Press, $1.50).—In this book are given brief accounts of the mineral resources of Africa by countries. Production and reserves are the matters chiefly presented, practically all geologic information being omitted. It would have been helpful if, instead of a very generalized bibliography at the end of the

pamphlet, the sources from which the items of information for the various countries have been obtained were specifically given.

ADOLPH KNOPF.

World Minerals and World Peace; by C. K. LEITH, J. W. FURNESS, and CLEONA LEWIS. Pp. xii, 253; 24 charts and maps. Washington, D. C., 1943 (The Brookings Institution, $2.50).—This small meaty volume presents a subject of very great importance. It deals with the world's raw mineral supplies and their bearing on international relations in war and peace. It analyzes the occurrence of mineral resources throughout the world, showing that they are very unequally distributed among the nations. Although changes are continuously being brought about by new discoveries and technologic advances, the authors regard it as probable that no very great shifts in the geography of mineral production will occur in the future. As no nation, even the most richly endowed, is self-sufficient, and as mineral resources "can not be legislated into existence," the interdependence of the nations on one another will continue as it has in the past. A timely, vigorous, and authoritative presentation, it can be recommended for wide reading.

ADOLPH KNOPF.

Eruptive Rocks, Their Genesis, Composition, and Classification, with a Chapter on Meteorites; by S. JAMES SHAND. Second edition. Pp. xvi, 444; 47 figs. New York, 1943 (John Wiley and Sons, Inc., $5.00).—*Eruptive Rocks* was first published in 1927, and the second edition now appearing in revised enlarged form is a welcome event. The new edition has been thoroughly brought up to date. The first ten chapters are a vigorous and stimulating presentation of fundamental principles. In places it is easy to see that Professor Shand strongly dislikes certain things: "magmatic differentiation," he says, "is a doubly unhappy expression." The remainder of the book deals mainly with the system of petrography devised by the author. According to the Shand classification, igneous rocks, or eruptive rocks as the author definitely prefers to call them, are divided into three classes: I, the oversaturated (rocks that contain primary free silica, generally quartz); II, the saturated, containing no free silica; and III, the undersaturated, consisting wholly or in part of unsaturated minerals (chiefly orthosilicates). These classes are further subdivided according to the relation between molecular alumina and the alkalis into peraluminous, metaluminous, subaluminous, and peralkaline rocks. The typical granodiorite of the classic Marysville stock, Montana, is for example according to this scheme a metaluminous tonalite. This classification cannot be said yet to enjoy wide acceptance.

The final chapter gives an excellent account of meteorites and shows how this knowledge bears on the interpretation of the pre-

geologic history of the Earth. The volume can be highly recommended for use by more advanced students. ADOLPH KNOPF.

Dolomites and Limestones of Western Ohio; by WILBER STOUT. Geol. Survey of Ohio, 4th ser., Bull. 42. 468 pages. Columbus, 1941.—This report gives a large amount of factual data on the geology and composition of the carbonate rocks of western Ohio. The dolomites, comprising more than 60 per cent of the stratigraphic column, are thought, on good supporting evidence, to be direct marine precipitates, deposited in shallow water. A notable feature of the report, to which attention is here directed, is the very large number of detailed chemical analyses of dolomites and limestones (analyst, Downs Schaaf), in which form 19 to 21 constituents have been determined. ADOLPH KNOPF.

Report No. 34 Research Council of Alberta. Geology; by JOHN A. ALLAN. Pp. 202. Edmonton, Alberta, 1943. $1.50.—This report is in five parts; they can be obtained separately. Part I—General geology of Alberta—is a condensed account of the geology of the province, whose rocks range in age from Precambrian to early Cenozoic. It is intended as an explanatory text for the recently issued new geological map of Alberta on the scale of 1 inch to 16 miles and printed in 32 colors. To make the present report more easily understandable it is accompanied by a black-and-white geologic map on the scale of 1 inch to 32 miles. Part II gives an account of the discovery by diamond drilling of a large salt deposit of high quality 200 feet thick in strata probably of late Silurian age. Part III deals with the geology of Alberta soils; Part IV describes a relief model of Alberta and its geological application; and Part V gives an account of the coal-bearing areas of Alberta. Coal occurs in three formations of the Cretaceous—Kootenay, Belly River, and Edmonton, and ranges in rank from subbituminous C to low volatile bituminous. Part V is accompanied by a map showing, on the scale of 1 inch to 20 miles, the distribution of the coal areas of the province. ADOLPH KNOPF.

PALEONTOLOGY.

[The Keilor skull and the Antiquity of Man in Australia.] *The Problem of Antiquity of Man in Australia*; by D. J. MAHONY. Mem. Nat. Mus. Melbourne, No. 13. Pp. 7-56, pls. 1-8, 1943. *The Keilor Skull: Anatomical Description*; by J. WUNDERLY. Ibid., pp. 57-70, pls. 4-9. *The Keilor Fossil Skull: Palate and Upper Dental Arch*; by WM. ADAM. Ibid., pp. 71-77, pls. 10-11. *The Keilor Fossil Skull: Geologic Evidence of Antiquity*; by D. J. MAHONY. Ibid., pp. 79-81.—In 1940 a fossil human skull was found at a depth of 18 feet in undisturbed terrace gravel near the village of Keilor and about 10 miles northwest of Melbourne, Australia. Later, another skull, fragments of limb bones, and a

crude chipped flint implement were found in the same layer. These remains are the subject of four closely related papers.

The first skull, here described, is almost complete, but the lower jaw is lacking. It represents a middle-aged male and combines Tasmanoid (negritoid) and Australoid characters in about equal proportions. It clearly belongs to the species *Homo sapiens*.

The surface of the terrace at Keilor is 108 feet above sea level and 45 feet above the bed of the adjacent stream. Doctor Mahony infers that the terrace corresponds to a former stand of the sea during the last interglacial age, but evidence for such antiquity is neither fully nor convincingly stated. The Keilor terrace, like two lower ones in the same valley, can be followed with a distinct gradient down stream until, where last observed, near Ascot Vale Gap, the Keilor terrace is only 60 feet above sea level. It appears, therefore, to be a normal stream terrace and its relation to any previous sea level is not evident from the data given. In view of the modern character of the skull and the lack of more convincing evidence of the Pleistocene age, we must await with interest a further contribution by Dr. R. A. Keble and Miss Hope Macpherson who carried out the field work in connection with the Keilor skull.

In the first article, Dr. Mahony gives a review of former discoveries of human fossils in Australia and of the conflicting views as to their antiquity. CARL O. DUNBAR.

Paleontology of the Harrar Province, Ethiopia; by BARNUM BROWN, et al. Bull. Amer. Mus. Nat. Hist., vol. 82, parts 1-4, pp. 1-98, pls. 1-25, 1943.—The Harrar Province of east central Ethiopia is a great tableland formed chiefly of flat-lying Jurassic strata which rest upon an undated complex of metamorphic and igneous rocks and are in turn overlain locally by Cretaceous deposits. Marine Jurassic rocks exceed 1200 feet in thickness, are largely calcareous, and are divisible into four zones, all of Late Jurassic age. They rest upon a series of non-marine arkosic sandstones and quartzites that locally bear fossil fish suggesting probably a Liassic (Early Jurassic) date.

The Cretaceous begins with some 350 feet of cross-bedded, loosely consolidated and unfossiliferous sandstone which is succeeded by nearly 100 feet of white, compact, and richly fossiliferous limestone. Still more locally this marine formation is succeeded by remnants of the unfossiliferous Nubian (?) sandstone.

The field work was done by Dr. Barnum Brown, who describes the geology in part 1 (pages 1-13). The faunas have been studied by a group of specialists, three of whom report here. Dr. Ethel D. Currie of the Hunterian Museum, University of Glasgow, describes the echinoids in part 2 (pages 14-29, figs. 1-11, and pls. 1-4); Dr. John W. Wells of Ohio State University describes the corals in part 3 (pages 37-58, pls. 5-9); and Dr. Gayle Scott of Texas Christian University describes the ammonites in part 4 (pages 61-93,

figs. 12-23, and pls. 10-25). The remaining groups of fossils will be treated in three parts yet to appear.

The American Museum deserves congratulations on the new and greatly improved format introduced with this volume of the Bulletin. Its larger page, soft paper, and full-tone plates improve both the usefulness and appearance of the Bulletin. CARL O. DUNBAR.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Hérédité Mendélienne et Analyse Combinatoire; Dr. E.-L. Roulet. Pp. 193. Geneve, Switzerland, 1941 (Georg & Cie S. A. Frs. suisses 12.-). The formulation of mathematical expressions for different gene combinations in gametes and zygotes in various systems of breeding is a regular procedure in genetics. Doctor Roulet, a mathematician come anew to Mendelian heredity, has been intrigued enough to derive formal expressions in terms of combinatorial analysis. A brief introduction concerning Mendelian heredity is followed by an exposition of the elements of combinatorial analysis, the symbols, and general formulae used by the author. The cases developed in detail are those where both parents are heterozygous for the same or differing numbers of genes and where one parent is heterozygous, while the other is homozygous recessive. The expressions derived are simple and economical of space and are summarized in three tables Although the chromosomal basis of inheritance is accepted in this work, no attempt has been made to treat the problems of linkage and the linear sequence of genes. It is hoped that Doctor Roulet will become interested in the analysis of changes in gene sequence or arrangement through the process of inversion which appears to be so important a feature in members of the genus Drosophila. D. F. POULSON.

PUBLICATIONS RECENTLY RECEIVED.

Iowa Geological Survey. Special Report. The Pleistocene Geology of Iowa; by G. F. Kay and others: Pt. I. The Pre-Illinoian Pleistocene Geology of Iowa; by G. F. Kay and E. T. Apfel; Pt. II. The Illinoian and Post-Illinoian Pleistocene Geology of Iowa; by G. F. Kay and J. B. Graham; Pt. III. The Bibliography of the Pleistocene Geology of Iowa; by G. F. Kay. Iowa City, 1943.

Virginia Geological Survey. Bulletin 58. Chloride in Ground Water in the Coastal Plain of Virginia; by D. J. Cederstrom, University, 1943.

Mr. Tompkins Explores the Atom; by G. Gamow. New York, 1944 (The Macmillan Co., $2.00).

Physics; by E. Hausmann and E. P. Slack. Revised edition U. S. Naval Academy. New York, 1944 (D. Van Nostrand Co., $5.50).

U. S. Geological Survey: 290 Topographical Maps.

Chicago Areal Geologic Maps: Surficial geology of quadrangles of the Chicago area; by J Harlen Bretz. Topographic base surveyed in coöperation with the U. S. Geological Survey in 1924-38; geologically survey in 1930-32. Scale 1/24000. Illinois State Department of Registration and Education. Maps 16, 20, 23-24.

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A MIOCENE INVERTEBRATE FAUNA FROM BURKEVILLE, NEWTON COUNTY, TEXAS.

H. B. STENZEL AND F. E. TURNER.

ABSTRACT. A mixed land, fresh water, and brackish water, vertebrate and invertebrate fauna occurs in the Fleming formation of southeast Texas. The age of this fauna is upper Miocene. The invertebrate portion of the fauna is described and discussed in this paper.

CLAY beds exposed near Burkeville, Newton County, Texas, carry a mixed fossil fauna of terrestrial vertebrates, river snails, and oysters and other brackish water fossils. The brackish water species persist toward the east in Louisiana, whereas toward the west the brackish water forms drop out and the fauna is almost exclusively composed of terrestrial vertebrate remains.

In addition one can trace the stratigraphic horizon of the Burkeville fauna down-dip and underground. With the aid of the invertebrate fossils it is possible to trace this same stratigraphic horizon into the subsurface section of the oil fields of the Texas and Louisiana coast country.

The following fossil remains have been found near Burkeville:

Vertebrates:

?Desmostylus	Sea cow, teeth
?Prosynthetoceras	Primitive horned ruminant, horn core and tooth
Blastomeryx?	Deer-like animal, toe bone and tooth
Camelidae indet.	Camel, bones
Merychippus perditus (Leidy)	Horse, jaw and teeth
Aphelops sp.	Rhinoceros, leg bone
Amblycastor stirtoni Hesse	Beaver-like animal, skull
Aves indet.	Bird, bone
Crocodilia indet.	Crocodile, skin plates and teeth
Chelonia indet.	Turtle, bones

Reptilian eggs	Reptile, eggs
Phyllodus sp.	Wrasse, teeth
Ameiurus cf. decorus Hay	Catfish, spines
Lepisosteidae indet.	Gar-pike, bones, scales, and skull.
Plinthicus cf. stenodon Cope	Eagle ray, tooth
Rhinoptera dubia (Leidy)	Eagle ray, teeth
Invertebrates:	
Potamides matsoni Dall	River snails
Goniobasis miocaenica Stenzel and Turner, n. sp.	River snails
Pleurocera acutum burkevillense Stenzel and Turner, n. subsp.	River snails
Unio sp.	River mussel
Ostrea normalis Dall	Oyster
Polydora sp.	Mudworm
Rotalia beccarii (Linné)	Foraminifer
Plants:	
Charophyte oogonia	

The vertebrate fossils of this fauna are described by C. J. Hesse[1] in a separate article. The reptilian eggs are described independently because they are a rare case of fossilization of delicate material. Finally, the stratigraphy and environmental conditions of the entire fauna are treated in another article.[2] This latter article gives also all pertinent local geologic information.

The age of the fauna may be determined in several different ways. For instance, the same stratigraphic horizon is known down-dip and underground in the oil fields of the Texas and Louisiana coast country where it is known as the "*Potamides matsoni* zone" and can be determined as Miocene on the basis of stratigraphic sequence and micropaleontologic evidence. On the surface the fauna and the beds which enclose it can be traced east and west and thus fitted into the stratigraphic sequence of the Gulf Coastal Plain. Among the invertebrates the most promising correlation is founded on *Ostrea normalis* Dall, which occurs at Burkeville as well as in the Hawthorn beds of Florida.

[1] Hesse, C. J.: Fossil vertebrates from Burkeville, Newton County, Texas. In preparation.

[2] Stenzel, H. B., Turner, C. J., and Hesse, C. J.: 1944, Brackish and non-marine Miocene in southeastern Texas. Bull. Amer. Petroleum Geol., vol. 28.

Description of Fossils.

Class GASTROPODA.

Family CERITHIIDAE.

Genus POTAMIDES Alexandre Brongniart, 1810.

Sur des terrains qui paroissent avoir été formés sous d'eau douce: Annales mus. histoire nat. Paris, vol. 15, pp. 367-370, pl. 1, fig. 3.

Genotype.—*Potamides lamarckii* Brongniart from the Oligocene of Longjumeau south of Paris and the forest of Montmorency north of Paris in France. Genotype by monotypy.

Potamides matsoni Dall.

Potamides matsoni + *matsoni* var. *gracilior* Dall, W. H. On a brackish water Pliocene fauna of the southern Coastal Plain: U. S. Nat. Mus. Proc., vol. 46, no. 2028, p. 231, pl. 21, figs. 1, 2, 7, 1913.

Types.—Dall's types, No. 166293, in U. S. National Museum, Washington, D. C.

Type locality.—Dall's types came from an old abandoned hand-dug well in the center of SE 1/4 NW 1/4 section 27, T. 3 N., R. 2 W., about 10 miles southwest of Alexandria, Rapides Parish, Louisiana, according to Mr. J. N. Ball, owner of the land.[3]

Geologic horizon.—Dall's type material came from the Castor Creek member of the Fleming formation, Miocene.

Remarks.—The variety *gracilior* Dall was not figured by Dall and its description consists of only three lines, quoted below:

"Shell with practically the same sculpture, but more regular and slender, and with the sculpture more uniform. Length 20, maximum diameter of base 7 mm."

Calvin Goodrich[4] has pointed out that in some living fresh water gastropods of North America the slenderness of the spire is dependent on living conditions. Hence, it seems that the distinction of a variety *gracilior* is not justified.

The *Potamides matsoni* Dall was found by Matson near Burkeville. His specimens were imprints in a conglomerate

[3] Compare Fisk, H. N.: 1940, Geology of Avoyelles and Rapides parishes: State of Louisiana, Dept. Cons., Geol. Bull. 18, pp. 164-165, fig. 36. In this report Fisk corrects Dall's description of the type locality. However, Fisk's map on fig. 36, is in slight disagreement with the text. Fisk's report is important for the stratigraphy of the exposed Miocene beds and their correlation toward the east.

[4] Goodrich, Calvin: 1934, Studies of the gastropod family Pleuroceridae—I: Univ. Michigan, Occasional Pap. Mus. Zool., no. 286, 18 pp., 1 pl.

matrix. The present authors were unable to find any *Potamides matsoni* Dall in spite of extended search. This is presumably due to the extremely uneven distribution of the fossils at the outcrops near Burkeville. Matson[5] mentioned that the entire area where he found the fossils was not larger than a few square feet.

Species of the genus *Potamides* live today in fresh and brackish water streams and swamps of tropical and subtropical regions.

Family PLEUROCERATIDAE.

Genus PLEUROCERA C. S. Rafinesque, 1818.

Discoveries in natural history in the western states: Amer. Monthly Mag. and Critical Rev., vol. 3, p. 355.

Genotype.—Pleurocera[6] *acuta* Rafinesque, living in Lake Erie, North America.

The genus *Pleurocera* was proposed together with six species, which were *nomina nuda* in 1818 and still are such. The first species described under the generic name *Pleurocera* was *Pleurocera verrucosa* Rafinesque (Rafinesque, C. S., Apolosia, the Mollusca: Ann. of Nat., no. 1, p. 11, 1820) from the Ohio River. This species is not one of the six *nomina nuda* given in 1818 nor does it fit into the genus *Pleurocera* according to the original generic definition given by Rafinesque in 1818. Therefore *Pl. verrucosa* Rafinesque is not admissible as the genotype species. The next species described under the generic name *Pleurocera* were *Pl. gonula* Rafinesque, *Pl. acuta* Rafinesque, and *Pl. rugosa* Rafinesque (Rafinesque, C. S., Enumeration and account of some remarkable natural objects in the cabinet of Prof. Rafinesque, in Philadelphia, pp. 2-3, 1831). Of these three *Pl. acuta* Rafinesque is readily recognizable and has been selected as the genotype species by Walker. The latter author has given a full and authoritative account of the genotype question in this genus (Walker, Bryant, The type of *Pleurocera* Rafinesque: Univ. Michigan, Occasional Paper Mus. Zool., no. 38, 10 pp., 1917).

The genus *Pleurocera* is widely distributed today in North

[5] Matson, G. C.: *in* Dall, W. H., *op. cit.*, p. 227.

[6] Rafinesque considered his genus consistently as of feminine gender. If *Pleurocera* is derived from the Greek κερας, horn, it must be of neuter gender. It has been treated as such by later writers.

America. It is found in the streams of the drainage area of the St. Lawrence River and in the Great Lakes. The easternmost occurrence in that area is in a tributary stream of Lake Champlain in Vermont; the northernmost reported occurrence is near Bayfield on Lake Superior in Wisconsin. The major area of distribution is in the Mississippi River drainage area. Numerous species have been described frcm the Ohio River and its tributaries, such as the Tennessee, Cumberland, Wabash, Green, and Allegheny at least as far east as Pittsburgh, Pennsylvania, and the western tip of Virginia and the northern tip of Georgia. On the western side of the Mississippi the genus is known in the drainage area of the river in Louisiana, Arkansas, Missouri, Kansas, and Nebraska. Adjacent to the Mississippi drainage area it is also found in the rivers of Alabama such as the Coosa and Alabama. It has not been reported as living in Texas. The nearest reported occurrence is about 80 miles east of Burkeville in the Red River at Alexandria, Louisiana.

Snails of this genus are fresh water inhabitants and have not been found in brackish waters. Their association with Unio in the calcareous clays of the vicinity of Burkeville indicates the same restriction to fresh waters in Miocene time.

Pleurocera acutum burkevillense Stenzel & Turner, n. subsp.

Pl. 1, figs. 7-12.

Description.—All the specimens are broken at the aperture and in most the apex is missing.

Shell polished, medium thick to thin, noticeably thinner than in the accompanying *Goniobasis*, varying in outline from elongate to slender elongate. Spire profile sigmoid, concave in neanic part, convex in adult; pleural angle 16° in the neanic, 34° in the ephebic and about 17° in the adult whorls. Protoconch missing in all adult shells known. One neanic shell with protoconch intact is available. Protoconch not clearly set off from later whorls, consisting of two to three convex, unornamented whorls making an elevated, nearly flat-topped, almost barrel-shaped protoconch. Nepionic whorls gently convex in profile and smooth. Sutures sharp and deep.

The convexity of the whorl profile decreases with growth. The profile of the adult whorls is straight or even faintly concave; concave zone a little posterior of the middle of each whorl.

Each adult whorl curves down sharply to the posterior suture and less sharply to the anterior one. Sutures are thus deeply incised and each whorl has a small, rounded subsutural shoulder.

Growth lines recede from the posterior suture at an angle of 60 degrees, cross in this way the subsutural collar, and form a shallow, rounded sinus between subsutural collar and concavity; hence they advance in a straight line to join the anterior suture at an angle of 60 degrees. In some specimens there are one or two shallow and discontinuously impressed spiral lines in the concave zone.

Body whorl about 1/3 the height of entire shell; straight or faintly concave in profile from subsutural collar to the level of the posterior end of aperture; at this level it is rapidly rounded, producing a well rounded basal angulation; outline of basal portion faintly sigmoid, convex near the angulation, and faintly concave toward the anterior canal. Aperture about 1/5 of height of entire shell. Inner lip not thickened, merely with a very thin shell deposit, whose outer edge is etched away in all specimens.

On the base of the body whorl the growth lines are gently convex orad. Near the canal, 2 to 3 faint, wide, and low spiral ridges produce small waves in the growth lines.

Dimensions.—Oldest figured syntype (fig. 11), length 19.2 mm., width 8.7 mm. (incomplete specimen).

Remarks.—The typical species *Pleurocera acutum* Rafinesque was described in 1831 from living specimens taken in Lake Erie.[7] As understood today the species consist of numerous living local races, many of which have been described by later authors as separate species. Thus the synonymy of the living *Pleurocera acutum* Rafinesque *sensu lato* includes very many other names. Thanks to the kindness of Dr. Calvin Goodrich there are specimens of three living local races of *Pleurocera acutum* Rafinesque at hand for comparison with the Burkeville Miocene material. The similarity of the latter material to those living representatives of *P. acutum* Rafinesque is striking. If *P. acutum* Rafinesque is considered in *sensu lato*, that is, inclusive of many different local races and even running into the living *P. canaliculatum* (Say), it is logical to consider the Burkeville Miocene Pleuroceras as belonging to the

[7] Rafinesque, C. S.: 1831, Enumeration and account of some remarkable natural objects in the cabinet of Prof. Rafinesque, in Philadelphia, pp. 2-8.

same species although they are geologically much older. However, it seems advisable to give the Burkeville Miocene Pleuroceras a definite, separate name, because such a separate name will make reference to this Miocene material easier. Therefore, the writers have given a new subspecific name to the Burkeville Miocene Pleuroceras. Possibly the Miocene Pleuroceras are ancestors of the present-day *Pleurocera acutum* Rafinesque.

Pleurocera acutum burkevillense Stenzel & Turner differs in minor features from some similar living local races of *Pleurocera acutum* Rafinesque. The former has more deeply sunk sutures on the spire whorls and a faintly concave whorl outline in adult whorls. Some specimens of the former have a slightly turreted spire. The latter have apparently no tendency to concave whorl outlines, the adult whorls being either flat or more often slightly convex in outline. Sutures are also much less deep and therefore less conspicuous in the latter.

Types.—Syntypes are at the Bureau of Economic Geology, The University of Texas, Austin, Texas. Unfigured syntypes in Museum of Zoology, University of Michigan, Ann Arbor, Michigan.

Type locality.—Locality 175-T-3 near Burkeville, Newton County, Texas.

Geologic horizon.—Bed (i) of section at type locality in *Potamides matsoni* zone, Fleming formation, Miocene.

Genus GONIOBASIS Isaac Lea, 1862.

Description of a new genus (Goniobasis) of the family Melanidae and eighty-two new species: Acad. Nat. Sci., Philadelphia, Proc. 1862, pp. 262-263.

Genotype.—*Goniobasis osculata* Lea, living in the Coosa River in Alabama, U. S. A. Genotype by subsequent designation in Hannibal, Harold, A synopsis of the Recent and Tertiary Mollusca of the Californian Province: Malac. Soc. London Proc., vol. 10, p. 179, 1912.

Goniobasis miocaenia Stenzel and Turner, n.sp.

Pl. 1, figs. 18-22.

Pachycheilus suavis Dall, W. H. On a brackish water Pliocene fauna of the southern Coastal Plain: U. S. Nat. Mus. Proc., vol. 46, no. 2028, pp. 232-233, pl. 21, figs. 6, 9, 1913.

Dall's original description of Pachycheilus suavis Dall: "Shell acutely conical, with about 10 whorls, the apical portion sculptured, the last 2 whorls smooth, except for incremental lines; nucleus very small (not seen); subsequent whorls (except

the last one or two) with about a dozen flexuous ribs with wider interspaces, crossed by 4 or 5 flattened spiral cords separated by narrow grooves; this sculpture is sometimes prolonged even to the last whorl, becoming gradually feebler, yet in the majority of cases it becomes obsolete on the eighth and is wholly absent on the last whorl. The latter is ovately rounded and sculptured only by incremental lines, though in young specimens there is sometimes a series of fine spiral grooves near the canal. Aperture narrowly ovate, acute behind; outer lip flexuous, sharp, produced in front, smooth inside; pillar arcuate, smooth, with a thick layer of enamel extending over the body; suture distinct, not appressed. Length (slightly decollate), 20; maximum diameter, 9.5 mm. Length of figured specimen, 16 mm."

"This is a form of rather unusual characters for the genus, but one of somewhat similar aspect among recent shells has recently been described by Doctor Pilsbry from Mexico."

Description of Goniobasis miocaenica Stenzel and Turner.—The material available is copious, but all specimens are broken off at aperture and apex.

PLATE 1.

Figs. 1-6. Reptilian eggs (?), x 1 1/5; fig. 1, 2 top view and bottom view of specimen 1; fig. 3, 4 top view and bottom view of specimen 2; fig. 5, 6 bottom view and top view of specimen 3; all from locality 175-T-1.

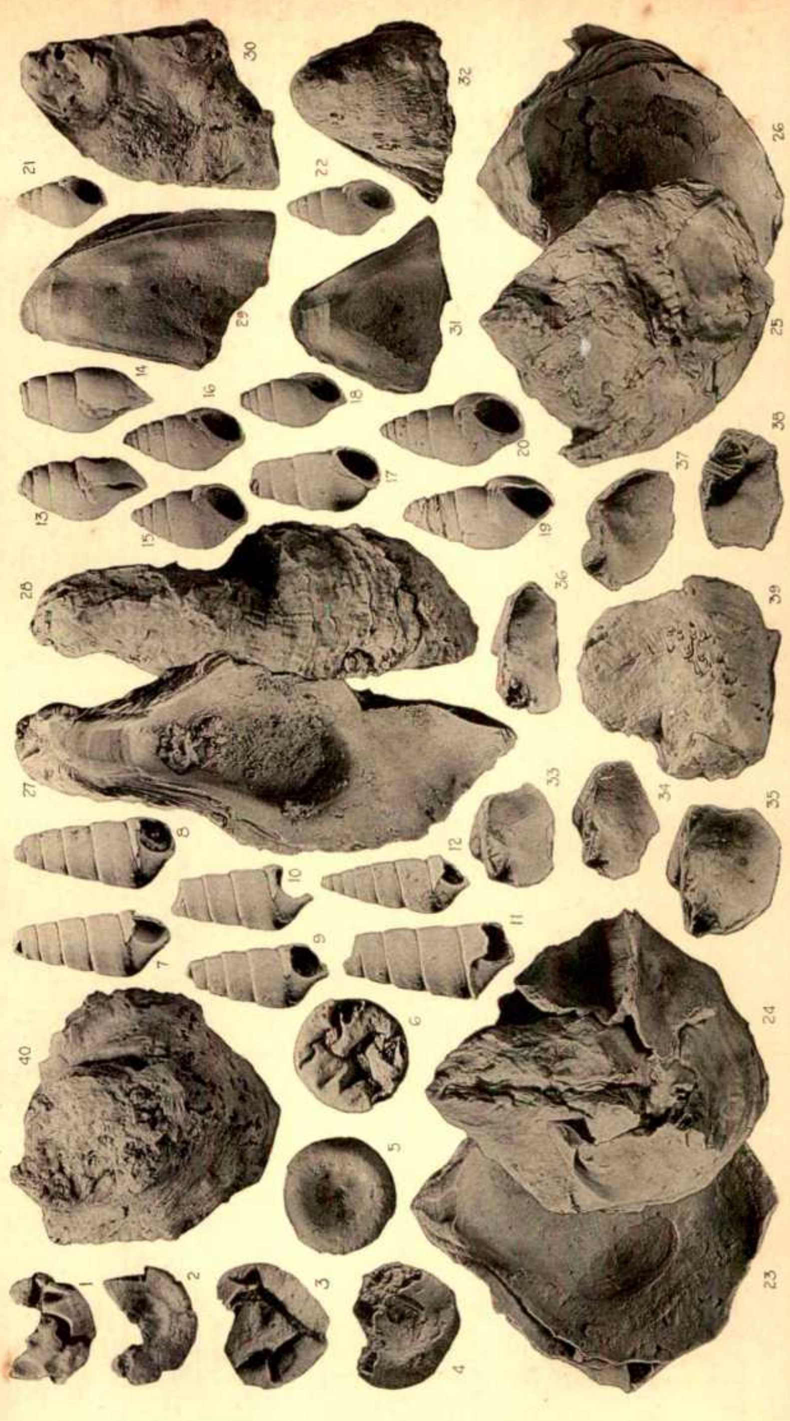
Figs. 7-12. *Pleurocera acutum burkevillense* Stenzel & Turner, n. subsp., x 1 1/5; 6 syntypes; all from locality 175-T-3.

Figs. 13-22. *Goniobasis miocaenica* Stenzel & Turner, x 1 1/5; 10 syntypes; all from locality 175-T-3.

Figs. 23-32, 39, 40. *Ostrea normalis* Dall, x 3/5; fig. 23, 24 inside and outside view of attached valve; fig. 25, 26 outside and inside view of attached valve; fig. 27, 28 inside and outside view of attached valve; fig. 29, 30 inside and outside view of part of free valve; fig. 31, 32 inside and outside view of part of free valve; fig. 39 outside view of attached valve, attachment scar at left; fig. 40 outside view of attached valve, large attachment scar at top center; figs. 23-32 from locality 175-T-3; figs. 39, 40 from locality 175-T-1.

Figs. 33-38. *Unio* sp., x 1 1/5; figs. 33-37 inside view of 5 right valves; fig. 38 inside view of left valve; from locality 175-T-3.

Figs. 30, 32, 39, 40. *Polydora* sp., x 3/5; borings of the mudworm *Polydora* in oyster valves; fig. 40 shows the twin portals of numerous galleries on the right lower side; fig. 39 is a partially etched valve showing the U-shaped ends of the galleries; fig. 32 shows a few twin portals crowded on left side; fig. 30 shows some twin portals and some galleries partially broken open. Figs. 30, 32 from locality 175-T-3; figs. 39, 40 from locality 175-T-1.



Shell polished, medium thick, varying in outline from elongate-conical to short-conical with the former the commoner. Spire profile variable from pronouncedly convex to straight-sided with the former the more usual; pleural angle 60 degrees in the neanic whorls of short-conical individuals, 55 degrees in the neanic whorls of elongate-conical individuals, 38 to 30 degrees in the adult whorls of corresponding individuals.

Protoconch missing, either broken off or corroded. Nepionic whorls each gently convex in profile and with about 16 to 21 gently curved ribs concave orad. On the earlier nepionic whorls the ribs are more closely spaced than on the later ones. These ribs and their interspaces are overlaid with about 6 unequal, flattened spiral cords, whose interspaces are wider than or equal to the ribs. Nepionic sculpture fades gradually with the spirals disappearing first.

Whorl profile convex, with a progressively more gentle curvature in the later volutions. Sutures sharply depressed but narrow. Surface polished and almost smooth. In most specimens there is a slight impressed, spiral line a short distance below the suture, but in some shells it is discontinuous or even lacking. The fine growth lines are sharply reflexed as they cross this spiral line, indicating that it was the locus of a tiny notch in the outer lip. A few specimens have a second, and feebler, impressed line lower on the whorl.

Body whorl about 2/3 the height of the entire shell; ovoid in outline, gently convex in posterior portion, uniformly convex at transition toward the base, faintly excavated near the canal. Few feebly impressed spiral lines near the canal. Growth lines sigmoid, gently concave orad in posterior, convex in anterior portion. Aperture about ½ of the height of the entire shell, oval and oblique, extends into a poorly defined, short, lobe-like anterior canal. Inner lip smooth with a thin, uniform callus deposit which extends below into the roundly reflexed canal wall. Outer lip smooth, medium in thickness, thickest at the suture. One old shell has its aperture well preserved. Whereas the outer lip is thin, the parietal wall has a heavy callus reflexed onto the wall of the body whorl. This callus constricts the posterior angle of the aperture. In younger specimens the callus is much thinner.

Dimensions.—Types of *Goniobasis miocaenica* Stenzel and Turner: largest, but incomplete syntype, height 28 mm., width

9 mm.; largest of the short-conical syntypes, height 18 mm., width 7.2 mm.

Remarks:—This species was first described by Dall as *Pachycheilus suavis*, n.sp. The present writers submitted several specimens from Burkeville to Calvin Goodrich for inspection. Through Calvin Goodrich's hands have gone many thousand specimens of recent river snails and obviously his statement, which follows here, is authoritative.

"An examination of your shells convinces me that they belong to *Goniobasis* rather than to *Pachychilus*. The plicate-striate sculpture is common in *Goniobasis*. It seems nowhere so clearly marked in *Pachychilus*, and far more often absent than present. The tight-coiling is sometimes a downstream character of *Goniobasis* and I find it among shells of the Coosa River, which may be considered a true river of juvenile habits. It may also be a reaction to brackish conditions, but I have only one instance to go on in this—shells taken from a salty pool of the Raritan River of New Jersey have this turretted aspect. On the side of *Pachychilus* is the thickness of your specimens, not at all common in *Goniobasis*."

"I notice that molluscan opercula have been found in fossil beds of California. They might possibly be in your deposits. If so, they should decide with definiteness whether *suavis* is *Goniobasis* or *Pachychilus*."

Pachychilus suavis Dall should be transferred to the genus *Goniobasis*. However, there is already a *Goniobasis suavis* (Lea),[8] which has been described in 1861 and has priority rights. Thus a new name has to be found for *Goniobasis suavis* (Dall). This has been done here; however the present writers have not merely substituted a new name but have carefully redescribed the species and deliberately chosen a new type locality. This was done because Dall's description is considered inadequate and because the type locality used by Dall was at the bottom of a farm well, now abandoned. The type locality chosen by the present writers is such that anyone enterprising enough may obtain topotype material readily. Thus all the data given herein are capable of being checked and possibly

[8] Lea, Isaac: 1861, Descriptions of 49 new species of the genus Melania. Acad. Nat. Sci., Philadelphia, Proc. 1861, p. 120.
———: 1868, New Melanidae of the United States: Acad. Nat. Sci., Philadelphia, Jour., ser. 2, vol. 5, pp. 228-229.

improved upon by the use of topotypes. Opercula have not been found in spite of careful search.

Types.—Syntypes of Stenzel and Turner at Bureau of Economic Geology, The University of Texas, Austin, Texas. Unfigured syntypes in Museum of Zoology, University of Michigan, Ann Arbor, Michigan. Dall's type, No. 166298, in U. S. National Museum, Washington, D. C.

Type locality.—Small black land prairie surrounded by woods, about 0.2 mile southwest of Little Cow Creek and about 0.2 mile southeast of the Burkeville-Newton highway (State highway No. 87), about 0.9 mile from the highway intersection in Burkeville (State highway Nos. 87 and 63), Newton County, Texas (Bureau of Economic Geology locality 175-T-3).

Dall's types came from an old abandoned hand-dug well in the center of SE¼NW¼ section 27, T. 3 N., R. 2 W., about 10 miles southwest of Alexandria, Rapides Parish, Louisiana, according to Mr. J. N. Ball, owner of the land.[9]

Geologic horizon.—Bed (i) of section exposed at type locality, *Potamides matsoni* zone, Fleming formation, Miocene.

Class PELECYPODA.

Family UNIONIDAE.

Genus UNIO.

Unio sp.

Pl. 1. figs. 33-38.

Description.—The small, decorticated, and highly nacreous valves are broken off at the margins so that neither the pallial line nor the adductor muscle imprints remain. However, the very posterior end of the pitted anterior adductor muscle imprint is present in many specimens. It lies anterior and slightly ventrad of the prominent hinge tooth.

Other specimens are preserved as interior casts composed of brown, limonite-cemented silt. These are usually somewhat crushed and show very few anatomical features. Their length is about 17 mm.

[9] Compare Fisk, H. N.: 1940, Geology of Avoyelles and Rapides parishes: State of Louisiana, Dept. Cons., Geol. Bull. 18, pp. 164-165, fig. 36. In this report Fisk corrects Dall's description of the type locality. However, Fisk's map on fig. 36 is in slight disagreement with the text. Fisk's report is important for the stratigraphy of the exposed Miocene beds and their correlation toward the east.

Dimensions.—Length of largest fragment 15 mm. This specimen may have attained a length of about 30 mm. when complete.

Type data.—Specimens at Bureau of Economic Geology, The University of Texas, Austin, Texas.

Type locality.—Localities 175-T-3 and 175-T-1, near Burkeville, Newton County, Texas.

Geologic horizon.—*Potamides matsoni* zone, Fleming formation, Miocene. The material from locality 175-T-1 occurred in upper part of bed (g) of the section; the material from locality 175-T-3 occurred in bed (i) of the section.

Family OSTREIDAE.

Genus OSTREA Linné 1758.

Systema naturae, edition 10, p. 696.

Genotype.—*Ostrea edulis* Linné, living in the seas of Europe. Genotype through subsequent designation by C. F. Schmidt 1818.

Ostrea normalis Dall.

Pl 1, figs. 28-32, 39, 40.

Ostrea georgiana, forma normalis Dall, W. H. Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene silex-beds of Tampa and the Pliocene beds of the Caloosahatchie River: Trans. Wagner Free Inst. Sci., Philadelphia, vol. 3, pt. 3, pp. 684-685, 1895.

Ostrea virginica, Dall, W. H. On a brackish water Pliocene fauna of the southern coastal plain: U. S. Nat. Mus. Proc., vol. 46, p. 230, 1913. Not *Ostrea virginica* Gmelin.

Ostrea mauricensis?, Dall, W. H. A monograph of the molluscan fauna of the *Orthaulax pugnax* zone of the Oligocene of Tampa, Florida: U. S. Nat. Mus. Bull. 90, p. 128, 1915.

Ostrea normalis, Gardner, Julia. The molluscan fauna of the Alum Bluff group of Florida: U. S. Geol. Survey Prof. Paper 142, p. 48, pl. 11, figs. 3-4, 1926.

Dall gave no description of his "*forma normalis.*" His treatment of this form consisted of a synonymy, in which California material predominated, a locality list, in which Georgia and Florida predominated over New Jersey and California localities, and some nondescriptive remarks. Through the lack of figures and descriptions the name "*normalis*" as used by Dall was a *nomen nudum.* Gardner was the first reviewer of this material and as such had the choice of ignoring or using the *nomen nudum.* Gardner chose to use Dall's type material and to retain Dall's original name for this form. Gardner's procedure is to be commended for many reasons.

Description of Burkeville material.—Specimens from localities 175-T-1 and 175-T-2 differ considerably from those of locality 175-T-3. However, the beds at all three localities are homotaxial. It seems highly improbable that there were two different though nearly related species of oyster living at the same time in such close proximity. Also, the differences between the oysters from the two localities are readily explained by differences in environmental conditions and are similar to those observable today in the *Ostrea virginica* Gmelin of our Gulf and Atlantic coast.

Specimens from locality 175-T-1 have a thin to medium thick shell. The attached valve has a large attachment scar in most cases occupying variously 1/3 to ½ of the length of the valve. The free portion of the valve rises steeply from the attachment, thus producing a deep, cup-shaped valve. Some shells have large, flat attachment scars extending over the entire length of the valve. The valve outline is elongate oval in youth but becomes nearly circular as the valve grows away from the attachment. Outer surface with poorly developed, concentric laminae which are faintly frilled at their margins. Ligament area curved and short, its basal width about twice its length. Margins of valve smooth.

Free valve gently convex from side to side, less convex in longitudinal direction. Margins are recurved so that there is a concave channel on the outer surface along the margins. Sculpture consisting of imbricate laminae in most cases badly eroded which are crossed in some specimens by fine, comparatively regular, continuous riblets of which there are about 8 to 10 per cm.

Specimens from locality 175-T-3 have a medium thick shell and are distinctly thicker than those from the other localities. The attached valves have usually long and narrow attachment scars produced by attachment to twigs, stems, or roots of plants. Such scars occupy variously ½ to more than ½ of the length of the valve. The free portion of the valve rises steeply from the attachment and produces a deep to medium deep, cup-shaped valve. The valve outline is elongate oval in youth and maturity. Outer surface with rough growth lines and incipient laminae which are faintly frilled. Ligament area short and nearly straight and nearly as long as it is wide or very long and narrow depending on the growth form of the shell. Valve margins smooth.

Free valve variable, flat to convex from side to side or in longitudinal direction. Margins recurved only in a few specimens. Outline oval to narrow, tongue-shaped with the ligament at narrow point. In these narrow specimens the ligament area has the characteristic shape described by Gardner. Sculpture on outer surface consists of rough imbricate laminae which are in some specimens crossed by riblets. At this locality many of the loose right valves are narrow and tongue-shaped and resemble the cat-tongue or coon-oyster shape of the present-day oyster, *Ostrea virginica* Gmelin.

Remarks.—This is the oyster which Dall listed as *Ostrea virginica* Gmelin from Burkeville in 1913. There is before us one of the oyster specimens from the U. S. National Museum collection No. 6440, probably collected by Matson. It is labelled *Ostrea* sp. and is an unidentifiable oyster imprint. If it is in any way representative of the other oyster material available to Dall, it is by no means a convincing argument for Dall's identification.

The real *Ostrea virginica* Gmelin is the common oyster living today along the east and south coast of North America from Canada to Mexico. It is also known from the Pliocene Caloosahatchee formation of Florida. The *Ostrea virginica* Gmelin has a strongly ribbed attached valve and differs very much from the material found near Burkeville. Dall's identification is incorrect if one can judge by the copious material which we collected near Burkeville.

The Gulf Coast Miocene formations contain several species of oyster. Most of these species are either very heavily ribbed and belong to the subgenus *Lopha* Bolten[10] or are very large and heavy shells. If one disregards the heavily ribbed or ponderous species, which are obviously unrelated to the Burkeville oyster, there remain the following species:

Ostrea vaughani Dall[11] from the Tampa limestone of Florida.

Ostrea normalis caducaqua Mansfield[12] from the Tampa limestone of Florida.

[10] Bolten, Museum Boltenianum, pt. 2, p. 168, 1798. Genotype is *Ostrea crista-galli* Linné through subsequent designation by W. H. Dall, Contributions to the Tertiary fauna of Florida, etc.: Trans. Wagner Free Inst. Sci., Philadelphia, vol. 3, pt. 4, p. 672, 1898.

[11] Mansfield, W. C.: 1937, Mollusks of the Tampa and Suwanee limestones of Florida: Florida Dept. Cons., Geol. Bull. 15, p. 203.

[12] Mansfield, W. C., 1937, *op. cit.*, p. 204.

"*Ostrea trigonalis* Conrad" as noted by Julia Gardner[13] as questionably occurring in the Chipola formation of Florida.

Ostrea normalis Dall[14] from the Hawthorn beds of Florida.

Ostrea disparilis Conrad[15] from the Choctawhatchee formation of Florida.

Considering the abundance of mollusks in most Miocene beds of the eastern part of the Gulf Coastal Plain, these 5 species do not make an impressive list. This fact is brought out still more if it is remembered that *Ostrea normalis caducaqua* Mansfield is described and known from a single right valve. While a single valve of an oyster may be an interesting indication of the presence of an as yet unrecorded species in the Tampa limestone, as paleontologic and comparative material it is nearly worthless.

The "*Ostrea trigonalis* Conrad" as noted by Gardner "is a poorly characterized form, not sufficiently well preserved to be identified with assurance" and "it is quite possible that the few valves in question may be more properly referable to the less ponderous *Ostrea haitensis* Sowerby." This so-called "*Ostrea trigonalis* Conrad" of the Miocene of Florida varies from smooth to heavily plicate and seems to belong to the subgenus *Lopha*. The oyster from the vicinity of Burkeville, however, never varies to plicate valves. For that reason it is perhaps possible to eliminate the so-called "*Ostrea trigonalis* Conrad."

These considerations reduce the number of known non-plicate, non-ponderous oyster species in the Miocene of the Gulf Coastal Plain to only three. *Ostrea normalis* Dall and *Ostrea disparilis* Conrad are apparently related, the former being not so regular in outline as the latter.

Unless they are a new species, the Burkeville oysters should belong to one of the three above-mentioned species. Although mere comparison of the two type figures of *Ostrea normalis* Dall in Gardner with figures of the Burkeville oysters does not reveal a striking similarity, certain characteristics are common to both. These characteristics are the faint, yet readily notice-

[13] Gardner, Julia: 1926, The molluscan fauna of the Alum Bluff group of Florida, pt. 1, Prionodesmacea and Anomalodesmacea: U. S. Geol. Survey Prof. Paper 142-A, pp. 41-42.

[14] Gardner, Julia: 1926, *op. cit.*, pp. 42-43.

[15] Mansfield, W. C.: 1932, Miocene pelecypods of the Choctawhatchee formation of Florida: Florida State Geol. Survey, Bull. 8, pp. 54-55.

able, frilling of the concentric laminae (see Pl. 1, figs. 23, 31), the lack of vermicular sculpture on the submargins, and the tendency to a habit of growth similar to *O. georgiana* Conrad (see Pl. 1, figs. 27-28). A great similarity among individual specimens of *O. normalis* Dall from Texas and Florida is hardly to be expected on account of the well known great variability of oyster shells and the great distance (about 700 miles) between the two places where this species is found.

Types.—Cotypes, No. 153843, of Gardner's description in U. S. National Museum, Washington, D. C. Material from near Burkeville, collected by Stenzel and Turner, in Bureau of Economic Geology, The University of Texas, Austin, Texas.

Type locality—Gardner's cotypes came from the Devil's Mill Hopper near Hawthorn, Alachua County, Florida. The material described in the present paper came from the three localities 175-T-1, 175-T-2, and 175-T-3, near Burkeville, Newton County, Texas.

Geologic horizon.—Gardner's cotypes came from the Hawthorn beds, Miocene. The species is widely distributed in the Hawthorn formation of Florida; Gardner listed 19 collections from that formation which contained the species.

The material described in the present paper came from the *Potamides matsoni* zone, Fleming formation, Miocene.

Class CHAETOPODA.

Order POLYCHAETA.

Family SPIONIDAE.

Genus POLYDORA L. A. G. Bosc, 1803.

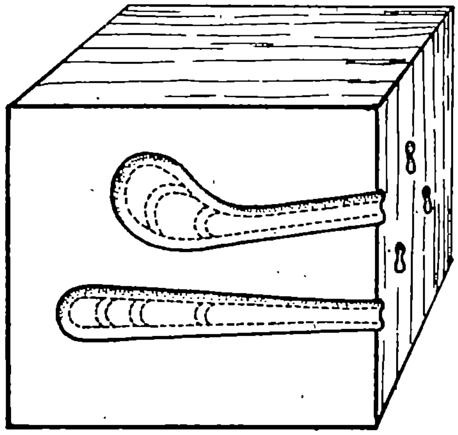
Histoire naturelle des Vers, vol. 1, p. 151, pl. 5, fig. 7, Paris, 1803.
Genotype.—Polydora cornuta Bosc from Charleston, South Carolina. Genotype by monotypy.

Concerning the genus and its type species, Dr. Olga Hartman[16] made the following statement:

"The genus was erected for the single species, *P. cornuta,* from Charleston, South Carolina. The description is too general to be more than generic, and if species of *Boccardia* were also to be found in eastern America, the first name would have little status. However, there are seemingly no Boccardias, but there are possibly 10 or more valid species of *Polydora* in the vicinity of Charleston. It

[16] Letter dated September 30, 1943.

is thus reasonably certain that Bosc did have a species of *Polydora* as it is at present interpreted, but what the species *cornuta* is, remains unknown. Bosc found the specimens in intertidal zones, among rocks, wood and shells; thus he might have had several species at his command. The collection on which he worked was presumably taken to France when Bosc terminated his American visit, but it is now supposedly lost. There have been no authentic descriptions of *P. cornuta,* in spite of subsequent revisions of the genus. (See Mesnil, 1896, Bull. Sci. France et Belgique, vol. 29, and Söderström, 1920, Studien über die Polychaetenfamilie Spionidae.) Claparède (1861, Reichert's Archiv. pp. 542-544) redescribed *P. cornuta* Bosc but had only specimens from Kilmore, Hebrides, which later proved to be *P. ciliata* (fide Mesnil, 1896, p. 220)."



Text fig. 1.—Diagram illustrating the shape of the bore holes made by the polychaetous annelid worm *Polydora.* Front face shows a longitudinal section of two galleries; side face of diagram shows several twin terminals.

Polydora sp.

Pl. 1, figs. 30, 32, 39, 40.

Description.—Many of the oyster shells have small bore holes. When intact the bore holes show at the outside merely as a pair of tiny interconnected holes having an outline like a dumbbell. As most of the oyster shells have their surface somewhat etched by weathering, the interior course of the bore holes may be inspected. There it is seen that the paired bore holes are merely the terminals of a U-shaped burrow. As in the case of the dumbbell-shaped terminal, the interior of the burrow,

that is, the lower parts of the U, is interconnected from side to side. The plane, in which the U lies, generally lies parallel with the coarse, imbricate shell lamellae of the oyster. The length of the U of a burrow is about 4 mm. to 10 mm.; the greatest diameter of the burrow measured at right angles to the plane of the U is ½ to 1 mm. The twin terminal is about 1.5 mm. wide. Behind the terminals the two branches of the burrow spread apart so that the outline is less like a U than like a tear drop. The greatest diameter is attained all along the U at the periphery, whereas the transverse part of the burrow connecting the two branches of the U has a smaller lumen.

Remarks.—Fossil bore holes of this shape have been known for sometime. Henri Douvillé[17] was probably the first to point out the significance of such burrows. He also showed examples of oysters bored by Polydoras. He suggested the use of the name *Polydorites* for burrows made by *Polydora* and related animals. Douvillé gave the following description of the manner in which these burrows are made by the *Polydora* annelid worm:

> ". . . . the animal excavates its burrows by means of robust hooks often equipped with teeth, which arm the fifth segment and frequently also the terminal segments. Therefore, it acts mechanically through a kind of scraping or rasping, and it is precisely these scrapings which it utilizes to fill up the median (transverse) and unused portion of its burrows; as the animal grows in length and width, it is really necessary that it deepens and widens its lodgings; on the other hand the transverse portion, which is not occupied by the animal, preserves its original width: it really represents the succession of the lower branches of the U in the various periods of the life of the animal." (P. 865.)

Polydora is today a typically shallow water animal. The depth range reported by D. Carazzi[18] from the region of Naples in Italy is 15 to 20 meters. According to the investigations by Lunz in South Carolina, *Polydora* is more prevalent in waters of low salinity and prefers oysters on a muddy or soft bottom over those on firm or hard bottom. Present-day conditions on the coast of the South Carolina coastal plain are presumably

[17] Douvillé, Henri: 1908, Perforations d'annélides: Soc. géol. France Bull., ser. 4, vol. 7, pp. 361-370, year 1907.

[18] Carazzi, D.: 1895, Revisione del genera *Polydora* Bosc e cenni su due specie che vivono sulle ostriche: Mittheilungen aus der zool. Station zu Neapel, etc., vol. 11, pp. 4-45.

similar to those of Miocene time on the coast of the Texas coastal plain.

Concerning the living species of this genus and their borings, Dr. Olga Hartman writes:

"No less than 25 species of *Polydora* (*sensu stricto,* since it is regarded distinct from the nearly related genus, *Boccardia*) have been described and recorded from the shores of North America. Of these at least 5 species are known to be perforating in calcareous objects. These are:

1. *P. websteri* Hartman (see Hartman, *in* Loosanoff and Engle, 1948, Biol. Bull., vol. 85, pp. 69-78) has been earlier recorded as *P. caeca* Webster (1879, Trans. Albany Inst., vol. 9, p. 258) from tortuous galleries in a sound upper valve of *Anomia*, in Virginia. Andrews (1891, Proc. U. S. Nat. Mus., vol. 14, p. 291) reported the same species common in perforated dead shells at Beaufort, North Carolina. During the summer of 1940 I found the species very common at Beaufort, and then (in MS) renamed it *P. websteri,* since *P. caeca* Webster was preoccupied by Oersted.
2. *P. concharum* Verrill (1880, Proc. U. S. Nat. Mus., vol. 2, pp. 174-176) was described from Cape Cod to Nova Scotia, in 10-100 fms. in tortuous narrow galleries, excavated in shells. Additional description of this form is in Hartman (1942, Bull. Bingham Oceanogr. Coll., vol. 8, no. 1, pp. 64-66, figs. 121-128).
3. *P. giardi* Mesnil perforates limestones and shales and is sometimes very common. It has been recorded from southern California (see Hartman, 1941, Hancock Pacific Exped., vol. 7, p. 309). This species has been widely reported from both hemispheres.
4. *P. armata* Langerhans similarly perforates calcareous structures. It has been reported from western America (see Hartman, 1941, Hancock Pacific Exped., vol. 7, p. 306).
5. *P. gracilis* Verrill (1880, Proc. U. S. Nat. Mus., vol. 2, p. 174) was decribed as gregarious in galleries of *Pecten,* off New England. The species remains incompletely known.

Fauvel (1927, Faune de France, vol. 16, pp. 49-55) describes 6 species of *Polydora* from western and southern France, perforating calcareous structures. These include *P. ciliata* (Johnston), *P. hoplura* Claparède, *P. giardi* Mesnil, *P. caeca* (Oersted), *P. flava* Claparède, and *P. armata* Langerhans."

Today oysters are infested by *Polydora* in a great many regions. Severe infestations have been reported from Europe, Australia, and the east coast of North America. Recent arti-

cles by Lunz[19] discuss this infestation as it occurs in South Carolina.

Lunz stated in 1941 that oyster shells from an Indian village site known to have been occupied prior to 1500 A. D, show infestation by *Polydora.* Douvillé's and our material indicate the presence of oyster infestations as far back as Miocene time.

Types.—The material is at the Bureau of Economic Geology. The University of Texas, Austin, Texas.

Type locality.—Locality 175-T-3, near Burkeville, Newton County, Texas.

Geologic horizon—*Potamides matsoni* zone, Fleming formation, Miocene.

ACKNOWLEDGMENTS.

The writers are greatly indebted to several scientists. Dr. Calvin Goodrich of the Zoology Museum, University of Michigan, Ann Arbor, Michigan, contributed considerable information about the river snails of the genera *Pleurocera* and *Goniobasis* and aided in placing the Burkeville species in their correct places. Dr. Olga Hartman supplied detailed information about living Polydoras and their burrows, thus expertly confirming the explanation of the fossil burrows. Dr. G. R. Lunz, Jr. also enlarged the information concerning these mud worms. Dr. Paul Bartsh and Dr. Julia Gardner gave the writers an opportunity to examine parts of the Burkeville Miocene fauna in the U. S. National Museum. The generous and speedy coöperation given us has made it possible to bring this paper to an early conclusion and to put it on a firmer scientific basis.

[19] Lunz, G. R., Jr.: 1940, The annelid worm *Polydora* as an oyster pest: Science, n.s., vol. 92, no. 2388, p. 310.
———: 1941, *Polydora,* a pest in South Carolina oysters: Elisha Mitchell Sci. Soc. Jour., vol. 57, no. 2, 273-283.

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THORIUM-URANIUM RATIOS IN ROCKS AND MINERALS.

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ABSTRACT. One hundred recent determinations of thorium-uranium ratios, including some new data, are assembled and plotted in frequency distribution curves. A probable value of 3.2 is indicated for basic, acidic, and intermediate rocks, but regional grouping of the results suggests that the ratio may be as high as 3.5. Independent confirmation that the Th/U ratio lies within this range is obtained from Nier's determinations of abundances of lead isotopes from samples of ore-lead.

For most purposes a constant value of 3.2 may be assumed for the Th/U ratio. This leads to no significant error in alpha-counting theory, in determinations of the rate of production of radiogenic heat, or in determinations of the rate of accumulation of helium and lead in rocks. The results do not support Holmes' theory of the genesis of lead ores from a deep-seated source.

THE ratio of concentrations of thorium to uranium in rocks is significant, not only in radioactivity investigations, but also in theories of genesis of lead ores. The most important question that arises in such considerations is whether or not thorium-uranium ratios of rocks generally fall within the range Th/U = 3 to Th/U = 4; if they do, certain problems in both the radioactivity and ore-genesis fields are greatly simplified. Since several procedures have been based upon the thesis that Th/U is close to 3.5, it is important to examine recent data to see to what extent this assumption is justified.

EARLIER ESTIMATIONS OF THORIUM-URANIUM RATIO.

Earlier calculations of Th/U are now known to be in error due to the inclusion of results proved to be inaccurate, sometimes by several hundred per cent,[1] Jeffreys' and Holmes' earlier figures are the results of uncritical averaging, and Evans and Goodman include some earlier data that do not fall within what now appears to be the normal distribution of results. For convenience, averages of Th/U reported prior to the present paper are summarized in Table 1.

Earlier determinations of radioactivity were frequently too high; apparently greater errors were present in uranium (or radium) than in thorium measurements, leading to low values for Th/U. As more reliable data accumulated, the accepted

[1] Evans, R. D., and Goodman, C.: 1941, Radioactivity of Rocks, Bull. Geol. Soc. of America, Vol. 52, pp. 459-490.

TABLE 1.

Previous Estimates of Th/U.

Observer	Year	Thorium-Uranium Ratio Acidic & Intermediate Rocks	Basic Rocks
Jeffreys*	1936	2.6	2.7
(Urry)†	1936	..	1.6
Holmes	1937	1.7	2.4
Keevil	1938	2.8	3.3
Holmes	1938	2.5‡	..
Nier	1938	3.8[6] (Lead ores)	
Evans & Goodman	1941	4.5	4.0
Evans, Goodman, and Keevil	1942	4	4

* Urry's and Evans' data omitted.
† Value obtained from data published by W. D. Urry, uranium corrected by 237 per cent. ref.[3], thorium unchanged.
‡ Probably since revised upwards, ref.[7].

value of Th/U has risen from between 1 and 2 to between 4 and 5, but it appears to the author that this upward revision has gone too far, and that the value for igneous rocks is close to 3.2.

SUMMARY OF THORIUM-URANIUM DATA SINCE 1937.

The results of recent determinations of radioactivity by the use of accepted procedures[2] are summarized in Table 2.

Direct determinations of thorium were made by streaming thoron with ionization chambers for alpha-ray counting, dilute solutions from analyzed thorium minerals being used as standards of comparison. Indirect determinations were made from measurements of the alpha-ray activity in alphas/mg./hr., a, and radium determinations by using the relationship

$$\mathrm{Th}=\frac{\mathrm{a}-1.04\mathrm{Ra}}{0.0886}$$

Th being in terms of 10^{-6} g/g, Ra in terms of 10^{-12} gram of radium per gram.

Uranium contents were calculated from radium, determined either by counting or ionization measurements (of alpha rays

[2] Evans, R. D., Goodman, C., Keevil, N. B., Lane, A. C., and Urry, W. D.: 1939, Intercalibration and Comparison in Two Laboratories of Measurements Incident to the Determination of the Geological Age of Rocks, Phys. Rev. Vol. 55, pp. 931-946.

TABLE 2.

Thorium and Uranium Contents of Rocks and Minerals.

Rock	Location	$Th \times 10^6$	$U \times 10^6$	Th/U
	1. Acidic and Intermediate Rocks.			
Rhyolite	Tower Creek Bridge Yellowstone Park	22±5	4.6 ±0.9	4.7*
Rhyolite	Golden Gate, Yellowstone Park	25±5	3.5 ±0.7	7.2*
Obsidian	Obsidian Cliff, Yellowstone Park	21±5	3.9 ±0.8	5.4*
Trachyte	Crescent Hill, Yellowstone Park	9.7 ±1.1	2.6 ±0.5	3.7*
Dacite	Bunsen Park, Yellowstone Park	10±1	1.7 ±0.3	5.9*
Tholeiite	Cleveland Dyke, Durham, Eng.	2.7 ±0.4	1.3 ±0.3	2.1*
Granite	Mt. Manitou, Colo.	20±4	3.8 ±0.5	5.4*
Granite	Glen Cove, Colo.	4.8 ±1.0	6.5 ±1.4	0.7*
Tonalite	Valverde Tunnel, Calif.	5±1	1.3 ±0.3	3.8*
Tonalite	Perris, Calif.	4.0 ±0.6	1.1 ±0.1	3.6*
Rhyolite	N. Attleboro, Mass.	9.0 ±0.1	1.85 ±0.18	4.9
Quartz dolerite	Whin Sill, Westmoreland, Eng.	0.9 ±0.1	0.48 ±0.11	1.9*
Granite	Quincy, Mass.	9.3 ±0.3 8.1 ±2.0	3.01 ±0.10 2.7 ±0.5	3.1 3.0*
Cognate xenolith	Quincy, Mass.	20.8 ±0.8	4.41 ±0.16	4.7
Granite	South Quincy, Mass.	11.75±0.72	3.55 ±0.11	3.3
Migmatite	Chelmsford, Mass.	26.2 ±1.7	15.1 ±1.1	1.7
Pegmatite	Chelmsford, Mass.	1.95±0.31	1.67 ±0.07	1.2
Granite-migmatite	Fitchburg, Mass.	19.0 ±0.25 21. ±5	3.1 ±0.5 2.5 ±0.5	6.1 8.4*
Pegmatite	Fitchburg, Mass.	1.24±0.11	3.07 ±0.08	0.4
Granite	Cape Ann, Mass.	17.1 ±1.0	5.05 ±0.55	3.4
Cognate xenolith	Cape Ann, Mass.	22.2 ±1.0 17 ±4	5.58 ±0.20 6.5 ±0.9	4.0 2.6*
Granite	Franklin, Maine	8.84±0.40	3.72 ±0.30	2.4
Granite	Hampstead, N. B.	17.0 ±0.3	4.63 ±0.20	3.7
Granite	Creighton Mine, Ont.	17 ±4	3.5 ±0.7	4.8*
Granite	Red River, Man.	4±1	0.5 ±0.1	8(*)
Granite	Barryfield Quarry, Ont.	3.12±0.07	1.53 ±0.24	2.1
Granite	Gananoque, Ont.	2.71±0.07	1.10 ±0.10	2.5
Syenodiorite	Blue Mt., Ont.	0.32±0.03	0.21 ±0.02	1.5
Granite	West of Taschereau, Que.	0.90±0.23	0.62 ±0.07	1.5
Granite	East of Taschereau, Que.	4.42±0.32	1.70 ±0.07	2.6
Granodiorite	Lake La Motte, Que.	2.04±0.29 2.5 ±0.3	1.34 ±0.08 1.6 ±0.3	1.5 1.6*
Granodiorite	Vassan Tp., Que.	2.2 ±0.2	0.72 ±0.03	3.1
Litchfieldite	Blue Mt., Ont.	0.19±0.02	0.105±0.015	1.8
	2. Basic Rocks.			
Porphyritic Basalt	Crescent Hill, Yellowstone Park,	8.5 ±1.5	2.3 ±0.5	3.7*
Basalt	¼ mi. W. of Geode Creek, Yellowstone Park	7.8 ±1.5	1.1 ±0.2	7.1*
Basalt	¾ mi. E. of Geode Creek, Yellowstone Park	10±2	0.57 ±0.11	17.5+

Thorium and Uranium Contents of Rocks and Minerals.

Rock	Location	Th×10^6	U×10^6	Th/U
Basalt	Overhanging Cliff, Yellowstone Park	4.30±0.24	1.18 ±0.08	3.6
Basalt	Columbia River	1.9 ±0.4	0.88 ±0.06	2.2*
Basalt	Gardiner, Yellowstone Park	2.9 ±0.5	0.40 ±0.08	7.1*
Basalt	Oldwick, N. J.	2.26±0.18	0.65 ±0.05	3.5
Basalt	Palisades, Staten Is., N. Y.	2.2 ±0.3	0.54 ±0.05	4.0
Diabase	Palisade Sills, N. J.	2.45±0.10	0.48 ±0.06	5.1
Basalt	Giants Causeway, Ireland	0.45±0.08	1.1 ±0.2	0.4
Diabase	Centerville, Va.	1.5 ±0.15	0.51 ±0.04	2.9
Lamprophyre	Eustis Mine, Que.	2.93±0.11	1.33 ±0.13	2.2
Andesite	Dalhousie Mt., N. S.	0.45±0.7	1.1 ±0.2	0.4*
Basalt	N. Attleboro, Mass.	3.22±0.20	0.78 ±0.08	4.1
Lamprophyre	Eustis Mine, Que. (pre-ore)	1.61±0.16	0.65 ±0.07	2.5
Monchiquite	Riasg Buidhe, Scotland	4.40±0.20 6.2 ±1.1	2.04 ±0.07 1.9 ±0.4	2.2 3.3*
Monchiquite	Kilchattan, Scotland	3.3 ±0.6 3.42±0.27	0.91 ±0.09 1.15 ±0.08	3.6* 3.0
Gabbro	St. Georges, N. B.	1.7 ±0.3	0.51 ±0.03	3.3
Gabbro-diorite	Blueberry Mt., Woburn, Mass.	1.6 ±0.3	0.45 ±0.08	3.6*
Norite	Outcrop, Creighton, Ont.	4.3 ±0.8	1.5 ±0.4	2.9*
Norite	40-level, Creighton Mine, Ont.	2.1 ±0.4	0.71 ±0.14	3.0*
Olivine diabase	20-level, Creighton Mine, Ont.	2.4 ±0.3	0.97 ±0.2	2.4
Olivine diabase	Worthington, Ont.	15±3	2.2 ±0.3	6.8
Trap	40-level Creighton Mine, Ont.	0.0 ±0.2	2.5 ±0.3	0.0*
Trap	Border of dyke, Long Lake, Wyo.	5.00±0.60	1.36 ±0.30	3.7
Trap dike	Long Lake, Wyo.	5.15±0.51	1.29 ±0.06	4.0
Trap dike	Beartooth Range, Wyo.	0.81±0.15	0.60 ±0.08	1.4*
Diabase	Horne Mine, Noranda, Que.	1.8 ±0.4 2.48±0.28	1.3 ±0.3 1.4 ±0.1	1.4* 1.7
Diabase	Yellowknife, N. W. T.	0.45±0.04	0.18 ±0.02	2.5
Trap	Gogebic Range, Mich.	3.2 ±0.3	0.91 ±0.17	3.5*
Diabase	Brotherton No. 2, Gogebic Range, Mich.	1.72±0.20	0.40 ±0.02	4.3
Diabase basalt	Ropruchei, U. S. S. R.	2.04±0.11	0.81 ±0.07	2.5
Norite	Quad Creek, Wyo.	2.13±0.30 0.96±0.15	0.47 ±0.06 0.37 ±0.03	4.5 2.6*
Pillow Lava	Huron Claim, Man.	0.08±0.02	0.02 ±0.006	4.0

3. Minerals.

Quartz	Quincy Granite, Mass.	3.40	1.78	2.0
Quartz	Cape Ann Granite, Mass.	5.75	2.27	2.5
Quartz	Lakeview Tonalite, Calif.	0.62	0.30	2.1
Feldspar	Quincy Granite, Mass.	6.19	1.08	5.7
Feldspar	Cape Ann Granite, Mass.	3.1	1.39	2.2
Feldspar	Lakeview Tonalite, Calif.	3.8	0.81	4.7*
Labradorite	Chapel Pond, N. Y.	1.16	0.78	1.5
Feldspar	Palisade Sill, N. J. and N. Y.	1.86	0.43	4.3
Feldspar	Yellowknife Diabase, N. W. T.	0.64	0.25	2.5*
Quartz and Feldsp.	Valverde Tonalite, Calif.	0.68	0.38	1.8*

Thorium and Uranium Contents of Rocks and Minerals.

Rock	Location	$Th \times 10^6$	$U \times 10^6$	Th/U
Felsic Concentrate	Huron Claim Lava, Man.	0.4(5)	0.02	20 (?)
Felsic Concentrate	Blue Mt. Syenodiorite, Ont.	0.29	0.15	2.0
Mafic Concentrate	Blue Mt. Syenodiorite, Ont.	0.43	0.41	1.0
Mafic Concentrate	Huron Claim Lava, Man.	0.02	0.02	1.0
Hornbl. and Biotite	Cape Ann Granite, Mass.	48	18.2	2.6
Aegirite and Riebeckite	Quincy Granite, Mass.	25.0	5.06	4.9
Biotite	Lakeview Tonalite, Calif.	0.58	0.9	0.6*
Pyroxene	Palisade Diabase, N. J. and N. Y.	2.63	0.54	4.9
Hornblende	Lakeview Tonalite, Calif.	5.05	1.36	3.7
Magnetite	Magnetite ore, Utah	2.7	1.88	1.5
Magnetite	Meme, T. N., Haiti	0.31	0.94	0.3
Magnetite	Fierro, New Mexico	0.94	0.34	2.7
Magnetite	Pr. of Wales Is., Alaska	0.64	3.5	0.2
Magnetite	Lynn Valley, B. C.	0.44	1.19	0.4
Magnetite	Texada Is., B. C.	0.36	1.2	0.3
Magnetite	Magnetite ore, Penna.	1.61	0.65	2.5
Magnetite	Goose Creek, Va.	2.25	0.43	5.3
Magnetite	Nova Scotia	1.2	0.32	3.7
Magnetite	Magnetite ore, Urals	0.31	0.53	0.6
Magnetite	Kiruna, Sweden	16.2	0.85	19
Magnetite	Hart Tp., Ont.	0.51	1.7	0.3

* Indirect determinations of Th/U, largely by Evans and Goodman ref. 1; measurements on Triassic diabases and magnetites by Goodman and Hurley (the latter grouped to avoid undue emphasis of magnetite).

from radon) referred to accepted radium standards, and converted by means of the relationship:

$$U = 2.84 \times 10^6 \text{ Ra}$$

The values of Th/U have a wide range. This should not be taken to mean, however, that these represent differences between *different rock bodies,* but rather between individual samples of rocks. True, the distribution of thorium and uranium seems to differ somewhat from rock to rock, but one cannot accept differences based on results for individual specimens unless one is sure of representative sampling.[3] In this regard it is interesting to note that when rocks are compared for which a number of determinations are available, the average values show less extreme differences, frequently falling in the range 2.5 to 5. For example, Evans and Goodman report a value of 0.5 for the Cape Ann granite, but a more detailed

[3] Keevil, N. B., Keevil, A. R., Ingham, W. N., and Grombie, G. P.: 1943, Causes of Variations in Radioactivity Data, Amer. Jour. Sci., Vol. 241, pp. 345-365.

study by the writer led to an average value of 3.4. One might consider from a single determination of Th/U for the Quincy granite, 4.8, that this rock shows a greater contrast of thorium with respect to uranium than the Cape Ann granite. Actually, other determinations of 2.0, 2.5, 2.8, 2.6, 2.6, 4.5, 3.3, 3.0, lead to an average value of 3.1, showing that the reverse is true and that the relative distribution is nearly the same.

For most purposes it is the average value of Th/U for a type of rock that is important. Such information is summarized in the third column of Table 3.

TABLE 3.

Summary of Thorium-Uranium Data.

Material	Number of Determinations	Average Value	Probable Value
Granitic Rocks	19	3.85	
Acidic Lavas	4	5.5	
Intermediate Lavas	3	3.9	
Intermediate Plutonic Rocks	5	2.5	
Pegmatites	2	(0.8)	
Acidic and Intermediate Rocks	34	3.4	3
Same, selected for more representative regional distribution	18	3.05	
Fine-grained Basic Rocks	20	3.8	
Medium or Coarse-grained	14	3.5	
Basic Rocks	34	3.7	3.3
Same, selected for more representative regional distribution	20	3.1	
Felsic Minerals	11	3.0	
Mafic Minerals	7	2.7	
Magnetite	12	3	
All Minerals	30	3.0	2.5*
Igneous Rocks	68	3.55	3.2
Rocks and Minerals	98	3.35	3.0

* Limits of error high for this case, as expected from geochemical considerations.

The first thing one notices on examining these data is that in all cases where enough data are available to yield a good statistical average, the value of Th/U falls within the range 3.0 to 4.0, whether granitic rocks, basic rocks, or minerals. This suggests that, although uranium and thorium are not governed

by any known physical or chemical relationship, nevertheless, the geochemical processes involved in their separation from a variety of crystallizing magmas are so regulated as to end up with one-third as much uranium as thorium.

One difficulty with the use of average values is that they are likely to be high because undue weight is attached to high values. This is particularly true when the number of determinations is small. It is preferable to use probable values obtained from distribution curves (Fig. 1).

Such data are given in the last column of Table 3. The most probable value for all igneous rocks suggested by present data is Th/U = 3.2.

It is clear from the distribution curves in Figure 1 that more data are needed for exact knowledge of this ratio, though it is sufficiently well known now for most purposes, as we shall see in the following section. It should be pointed out also that the rocks studied thus far by reliable methods do not sample the earth's surface systematically. The writer has attempted to obtain a better average by grouping the rocks according to regions (but even so the bulk are North American rocks); when this is done, the average for eighteen granites is Th/U = 3.05, the average for twenty basalts, 3.10.

CONFIRMATION OF AVERAGE TH/U RATIO FROM ISOTOPIC DATA.

It is now believed that common lead from such ores as galena is made up of *primal lead contaminated with radiogenic lead.*[4] If one assumes primal lead to be represented by those old lead ores that contain the smallest amounts of uranium lead (Pb^{206}) and thorium lead (Pb^{208}) with respect to the isotope (Pb^{204}) of presumed non-radiogenic origin, then the radiogenic lead present in geologically younger minerals can be obtained by difference. This offers a means of obtaining the thorium-uranium ratio in the source from which the lead mineral was derived.

$$\mathrm{Th/U} = 3.08\ \frac{Pb^{208}}{Pb^{206}}$$

where $$\frac{\lambda_U}{\lambda_{Th}} = 3.08$$

[4] Nier, A. O.: 1938, Variations in The Relative Abundances of Isotopes of Common Lead from Various Sources. J. Am. Chem. Soc., Vol. 60. 1571-1576.

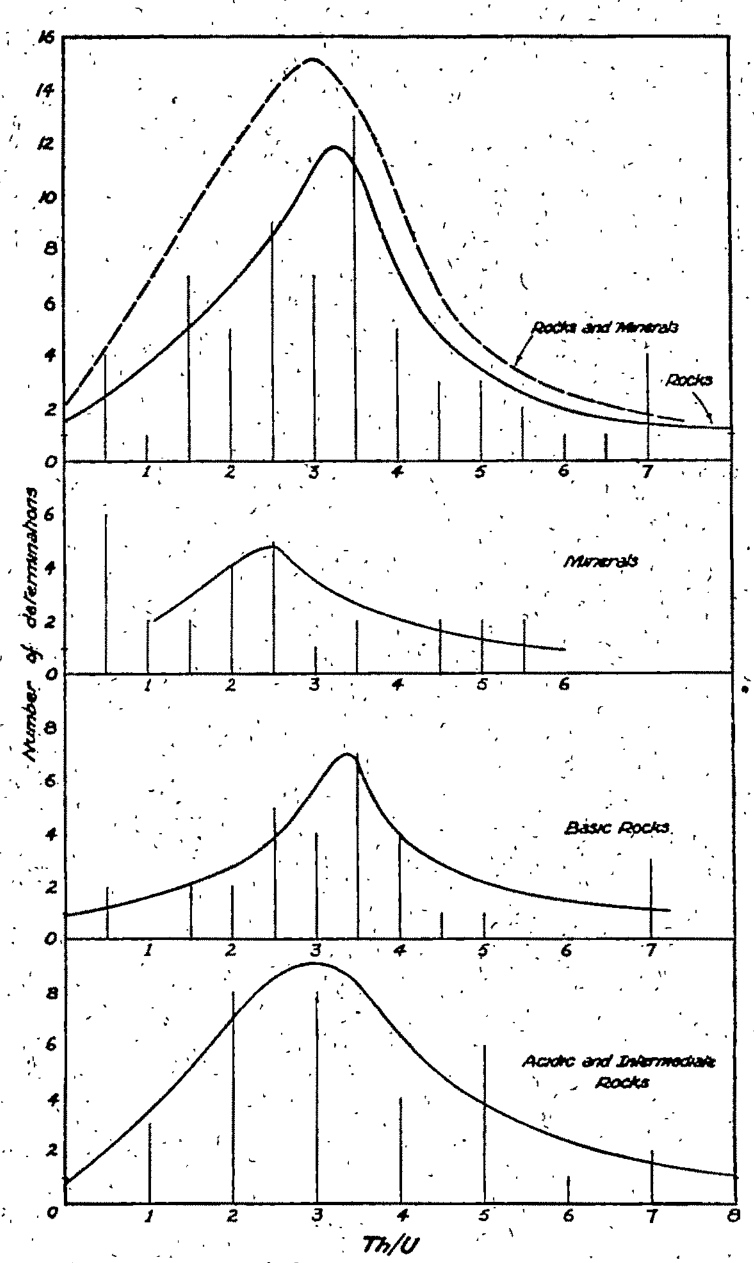

Fig. 1. The relative distribution of thorium and uranium in rocks and minerals.

The closest approximation to primal lead appears to be the lead analyzed from Ivigtut, Greenland,[5] for which the pertinent data are:

Thorium Lead	Uranium Lead
(Pb^{208}/Pb^{204}	(Pb^{206}/Pb^{204})
34.5	14.6

The radiogenic lead in a sample from Joplin, Missouri, in which the thorium lead was found to be 41.8, and the uranium lead 22.3 times as abundant as Pb^{204}, the excess thorium lead is clearly 7.3, the excess uranium lead 7.7, leading to an average Th/U ratio in the source of 2.9. Due to the differences in the decay rates of uranium and thorium, the present-day ratio of the parent elements would be:

$$\frac{\mathrm{Th}}{\mathrm{U}} = 2.9\frac{e^{\lambda_U t}}{e^{\lambda_{Th} t}} = 3.3$$

when t is taken as 1250 million years—a time intermediate between the age of the earth and the age of the mineral.

Thorium-uranium ratios calculated in this way for twenty-four samples of common lead are given in Table IV. The average value for Th/U in the source that contributed contaminating radiogenic lead is 2.7 and the ratio extrapolated to the present, 3.15. There is some uncertainty in the definition of "primal," and if one uses Great Bear lead as such, the Th/U ratio in the source material and at the present is calculated to be 3.5 and 4.0 for nineteen samples.

The important thing to note, however, is that these values, 3.15 and 4.0, straddle the ratios determined by direct radioactive methods (Table 3).

SIGNIFICANCE OF THORIUM-URANIUM RATIO.

Lead Ore Genesis—Holmes[6] noted that the atomic weight of ore-lead was nearly constant, 207.20−207.22, and that *unless the Th/U ratios were universally near 4*, a greater variation in the range of atomic weights would be expected if the lead were derived from rocks, since ore lead would consist of common

[5] Nier, A. O., Thompson, R. W., and Murphy, B. F.: 1941, The Isotopic Constitution of Lead and the Measurement of Geological Time. III, Phys. Rev., Vol. 60, pp. 112-116.

[6] Holmes, A.: 1937, The Origin of Primary Lead Ores, Econ. Geol., Vol. 32, pp. 763-782.

TABLE 4.

Thorium-Uranium Ratios as Deduced From Relative Abundances of Isotopes in Common Lead Ores.

Mineral	Location	Excess Th/D / Excess RaG	Th/U (extrapolated to present)
Wulfenite and Vanadinite	Tucson Mts., Arizona	0.95	3.3
Bournonite	Casapalca, Peru	0.90	3.2
Galena	Casapalca, Peru	0.99	3.45
Cerussite	Wallace, Idaho	0.56	1.95
Galena	Metaline Falls, Washington	1.06	3.7
Galena	Sonora Mine, Castle Dome, Ariz.	1.01	3.55
Galena	Durango, Mexico	0.97	3.4
Galena	Freiberg, Saxony	1.01	3.55
Galena	Saxony, Germany	1.04	3.65
Galena	Alpine Trias, Austria	1.12	3.95
Galena	Przibram, Bohemia	1.01	3.55
Galena i	Joplin, Missouri	0.90	3.15
Galena ii	Joplin, Missouri	0.84	2.9
Galena iii	Joplin, Missouri	0.92	3.2
Galena	Harz Mts., Germany	1.06	4.0
Galena	Eifel, Germany	0.88	3.15
Galena	Nassau, Germany	0.96	3.35
Galena	Yancey County, N. C.	0.97	3.3
Galena	Franklin, N. J.	0.81	2.7
Galena	Tetreault Mine, Quebec	0.68	2.5
Cerussite	Broken Hill, N.S.W.	0.60	2.2
Galena	Broken Hill, N.S.W.	0.70	2.6
Galena	Great Bear Lake, N.W.T.	0.68	2.4
Native Lead	Langban, Sweden	0.90	3.5
		Ave. Th/U	3.17

lead *"contaminated" with radiogenic lead.* Actually, determinations of the atomic weight by the physical method (isotopic analysis) have shown a range 207.175 to 207.236, due to such contamination. Furthermore, the surprising tendency of thorium-uranium ratios to fall near a probable value of 3.2 can account for the small range in atomic weight values. Even a value of Th/U = 2.7 for typical granitic rocks would not result in an atomic weight less than 207.175! Holmes has attempted to find a flaw[7] in arguments along this line[8] by point-

[7] Holmes, A.: 1938, The Origin of Primary Lead Ores: II, Econ. Geol., Vol. 33, pp. 829-867.

[8] Keevil, N. B.: 1938, Thorium-Uranium Ratios of Rocks and their Relation to Lead Ore Genesis, Econ. Geol., Vol. 33, pp. 685-696.

ing out the variations in Th/U for individual samples; the fallacy of focussing one's attention on such results and the necessity of using representative values has been pointed out above, and as accumulating results tend only to support the thesis that the average value of Th/U exceeds 2.7, Holmes' arguments seem to rest on insecure ground.

RATE OF PRODUCTION OF HELIUM AND LEAD.

Determinations of geological age by the lead or helium methods depend upon the relationship:

$$\text{age} = \frac{\text{accumulated end product}}{\text{rate of accumulation}}$$

The denominator of this equation can be obtained either by determining the amount of a member of the uranium series and a member of the thorium series, or by determining the rate of emission of alpha-rays, since $a = 0.365U + 0.0886Th$ alphas/mg./hr, where U and Th are expressed in parts per million. Because of the difference in decay rates of uranium and thorium it was thought at first, that if the alpha-count method was used, a separate determination of U(or Ra) or Th was necessary. The writer showed[9] that if Th/U be assumed to be 3.5, no measurement in addition to a is necessary even for old rocks. In a rock 1500 million years old the error in making such an assumption is less than 3 1/3 per cent within the range Th/U=0 to Th/U=10.

In this connection the results summarized in the present paper are most encouraging. They support the earlier estimate of Th/U=3.5 and show that there is a negligibly small chance of the ratio exceeding 10 for an igneous rock. It is, therefore, satisfactory in this respect to use the simpler alpha-count method for age determinations of old as well as young rocks without additional radioactivity measurements.

Alpha-Counting Theory—To obtain the true rate of alpha-ray emission from solid sources, it is necessary to correct the observed alpha-count for the absorption of alpha-rays by the deposit. This correction depends to some extent on the relative proportions of the uranium series and thorium series in the deposit, since the number of emitters and ranges of the alpha rays differ in the two series.

[9] Keevil, N. B.: 1939, The Calculations of Geological Age, Amer. Jour. Sci., Vol. 237, pp. 195-214.

Since the distribution of thorium and uranium and actino-uranium is not entirely random and unpredictable (Fig. 1) and the summated ranges do not differ widely between the two series, it is satisfactory to assume Th/U=3.5, particularly since at this ratio of concentrations the rate of production of alpha-rays by the uranium and actino-uranium series is nearly the same as the rate of alpha-ray emission from the thorium series. It can be shown from the expected variations in Th/U suggested by Figure 1 that the errors in making this assumption are less than present experimental errors.

Rate of Production of Radiogenic Heat—Since the heat generated by radioactive disintegration in rocks is largely due to the energy emission of alpha-rays, the arguments in the two foregoing sections suggest that a determination of the alpha-ray activity would probably lead to a value for the rate of production of radiogenic heat. The application of such a method depends upon the distribution of thorium and uranium in rocks, and their relative rates of heat production. The fact that the ratio of Th/U falls within a fairly narrow range of values, on either side of Th/U=3.3±0.5 makes the method generally applicable within satisfactorily low limits of error[10]:

$$H' = 2.15a \pm 2 \text{ per cent}$$

where H′ is the rate of heat production from the uranium, actino-uranium, and thorium series in calories per gram per million years. This is an important development, for the more laborious procedures for radium and thorium determinations can now be substituted by the alpha-counting method for the accumulation of fundamental geothermal data. The writer has under way at present such a program under a grant from the Geological Society of America.

SUMMARY AND CONCLUSIONS.

1. The probable value for Th/U ratio of an igneous rock is indicated by existing data to lie between 3.0 and 3.5.

2. The average relative concentrations of thorium and uranium in large bodies of rock do not lend support to Holmes' theory of lead ore genesis.

3. Assuming a constant value of Th/U=3.5 in determina-

[10] Keevil, N B.: 1943, Radiogenic Heat in Rocks, Jour. Geol., Vol. 51, pp. 287-300.

tions of the correction factor for absorption of alpha rays by rocks, the rate of helium production, or the rate of production of radiogenic heat, results in errors less than present experimental errors.

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2. Evans, R. D., Goodman, C., Keevil, N. B., Lane, A. C. and Urry, W. D.: 1939, Intercalibration and Comparison in two Laboratories of Measurements Incident to the Determination of the Geological Ages of Rocks, Phys. Rev., Vol. 55, pp. 931-946.
3. Keevil, N. B., Keevil, A. R., Ingham, W. N., and Crombie, G. P.: 1943, Causes of Variations in Radioactivity Data, Vol. 241, pp. 345-365.
4. Nier, A. O.: 1938, Variations in the Relative Abundances of the Isotopes of Common Lead from Various Sources, J. Am. Chem. Soc., Vol. 60, 1571-1576.
5. Nier, A. O., Thompson, R. W., and Murphey, B. F.: 1941, The Isotopic Constitution of Lead and the Measurement of Geological Time. III, Phys. Rev., Vol. 60, pp. 112-116.
6. Holmes, A.: 1937, The Origin of Primary Lead Ores, Econ. Geol., Vol. 32, pp. 763–782.
7. Holmes, A.: 1938, The Origin of Primary Lead Ores: II, Econ. Geol., Vol. 33, pp. 829-867.
8. Keevil, N. B.. 1938, Thorium-Uranium Ratios of Rocks and their Relations to Lead Ore Genesis, Econ. Geol., Vol. 33, pp. 685-696.
9. Keevil, N. B.: 1939, The Calculation of Geological Age, Amer. Jour. Sci., Vol. 237, pp. 195-214.
10. Keevil, N. B.: 1943, Radiogenic Heat in Rocks, Jour. Geol., Vol. 51, pp. 287–300.

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UNUSUAL FEATURES IN EJECTED BLOCKS AT KILAUEA VOLCANO.

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ABSTRACT. Picritic basalts near the feeding conduit of Kilauea Volcano appear to have become reconstituted in the solid state, as a result of remaining for a long period at a high temperature, during which the original pigeonite broke down and yielded hypersthene and augite. The texture of the resulting groundmass resembles that of contact metamorphic hornfelses. A reddened picritic basalt shows deposition of iron ore throughout the olivine phenocrysts.

INTRODUCTION.

PHREATIC explosions at Kilauea Volcano, in April 1924, hurled out blocks of solid rock, some of them weighing several tons, which had been torn from the walls of the conduit by the explosion.[2] The blocks include many different types, most of them identical to the various lavas that form the slopes of the volcano. A few blocks of coarse-grained gabbro also are present. Most of the ejected blocks were nearly cold, and only a very small proportion were hot enough to be incandescent.

Petrographic examination of the ejected blocks has revealed unusual features in some of them, which are briefly described in the following paper. Dr. Cordell Durrell of the University of California at Los Angeles, and Dr. H. T. Stearns of the U. S. Geological Survey, have kindly read and criticized the manuscript.

DESCRIPTION OF THE BLOCKS.

During the collapse there was exposed in the walls of Halemaumau pit a small sill-like intrusive which was red hot, and most or all of the blocks ejected in an incandescent state were derived from this intrusive.[3] These blocks can now be found on all sides of Halemaumau, but appear especially numerous on the western rim. Even in hand specimens they differ greatly in appearance from the other ejected blocks. They are pale

[1] Published by permission of the Director, Geological Survey, U. S. Department of the Interior.

[2] Jagger, T. A., and Finch, R. H.: 1924, The explosive eruption of Kilauea in Hawaii, Amer. Jour. Sci., 5th ser., vol. 8, pp. 353-374, 1924.

Stearns, H. T.: 1925, The explosive phase of Kilauea Volcano, Hawaii, in 1924, Bull. volcanologique nos. 5 and 6, pp. 193-209.

[3] Stearns, H. T. personal communication.

yellowish-green. They have an irregular blocky fracture, and show the exceptionally dense aspect frequently seen in contact metamorphic hornfelses. The numerous olivine phenocrysts, which range in size up to 7 mm. long, are also peculiar in appearance. They are greenish-brown, with a more conchoidal fracture than is characteristic of Hawaiian olivines, and have an unusually brilliant luster, which is almost submetallic in some specimens. Many are distinctly iridescent on the conchoidal fractures.

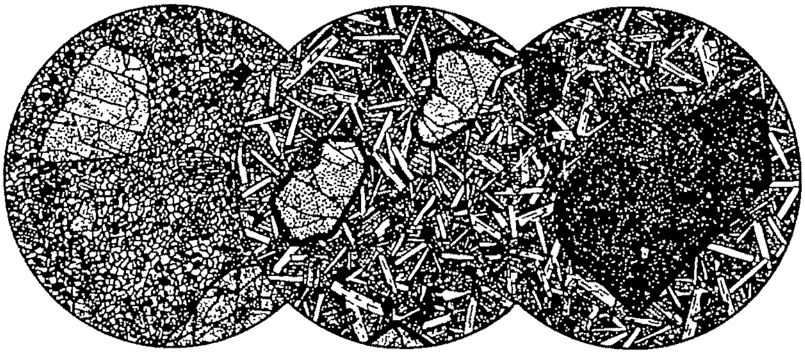

Fig. 1. (a) Block of picritic basalt ejected in an incandescent condition from Halemaumau during the 1924 explosions; olivine phenocrysts lie in a hornfels-like groundmass of augite, hypersthene, labradorite, and iron ore, some of the hypersthene showing sieve structure, (b) Normal intergranular picritic basalt of a prehistoric lava flow of Kilauea; olivine phenocrysts are partly resorbed with attendant liberation of a shell of finely granular iron ore. (c) Block of reddened picritic basalt from the 1924 explosion debris; the olivine phenocrysts contain abundant finely granular iron ore scattered throughout the crystals. Ordinary light, X 25.

In thin sections the olivine phenocrysts are seen to be rounded and embayed by magmatic resorption, but appear otherwise unaltered. They show an optic axial angle close to 90°.

The groundmass consists of plagioclase, pyroxene, and iron ore. The texture is quite unlike the textures of the normal Kilauean lavas, which typically are intergranular or intersertal (Fig. 1b). Instead, subhedral to anhedral grains of pyroxene lie in a mosaic of anhedral plagioclase (Fig. 1a). Sieve textures consisting of hypersthene grains enclosing many small crystals of plagioclase and iron ore are also present. The groundmass pyroxene is of two varieties, hypersthene and augite. Both are

pale greenish-brown; the hypersthene is faintly pleochroic. The augite has $+2V=60^\circ\pm$. The hypersthene has $-2V=80^\circ\pm$, with $r>v$ weak, corresponding to an $MgSiO_3$ content of about 78 per cent. The plagioclase is intermediate labradorite ($\beta=1.564$). The iron ore includes both magnetite and ilmenite. A few small prismatic grains of apatite also are present. The estimated mineral composition of the rock is as follows: olivine 30 per cent, augite 18 per cent, hypersthene 14 per cent, plagioclase 31 per cent, iron ore 6 per cent, and apatite 1 per cent.

Ejected blocks similar to the picritic basalt just described, except that olivine phenocrysts are less abundant, probably came from the upper part of the intrusive. In these blocks the resorption of the olivine phenocrysts liberated abundant finely granular iron ore which was deposited around the edges of the grains and along fractures. Many of the olivine phenocrysts are surrounded by a rim of hypersthene of coarser grain size than the rest of the groundmass, and a few of the original phenocrysts have been entirely replaced by granular aggregates of hypersthene and iron ore, the outlines of the phenocrysts being preserved by the ore grains.

Reddened blocks of picritic basalt, which were probably cold when ejected, contain olivine phenocrysts that show a type of alteration uncommon in Hawaiian rocks but identical to that in lavas near Auckland, New Zealand, described by Bartrum.[4] Similar olivines have been noted in olivine basalt from Umiahu Cone on Hualalai, and in picritic basalt from the northwest side of Kaawalii Gulch on Mauna Kea. The separation of finely granular iron ore around the edges and less frequently along fractures in the grains is a common phenomenon in Hawaiian lavas, accompanying the resorption of olivine phenocrysts. In this rock the ore forms rims around the phenocrysts, as is usual, but it is also distributed throughout the phenocrysts as irregular masses and small vermiform threads, in part following fractures but largely independent of any detectable fractures (Fig. 1c). The olivine shows $-2V$ of $85^\circ\pm$, corresponding to about 74 per cent forsterite, and thus has about the same composition as the usual olivine phenocrysts of Hawaiian lavas.[5] The

[4] Bartrum, J. A.: 1942, Unusual olivine in basalt near Auckland, New Zealand, Jour. Geology, vol. 50, pp. 914-917.

[5] Aurousseau, M., and Merwin, H. E.: 1928, Olivine; I. From the Hawaiian Islands; II. Pure forsterite, Am. Mineralogist, vol. 18, p. 560.

red color of the rock is caused by abundant hematite scattered throughout the groundmass. The hematite is probably largely derived by alteration of the iron-bearing minerals of the groundmass.

CONCLUSIONS.

The groundmass texture of the hypersthene-bearing picritic basalt is entirely different from the textures of the normal lavas of Kilauea. The latter generally have intergranular or intersertal textures (Fig. 1b), resulting from crystallization in a liquid, the relative euhedrisms of the grains arising largely from their order of precipitation. The texture in the ejected blocks is, however, a typical hornfels texture, resulting from crystallization in a solid medium in the absence of appreciable differential stress, the shapes of the minerals being the result of their relative strengths of crystallization. It is a texture commonly found in volcanic rocks that have undergone thermal metamorphism, or dynamothermal metamorphism without much internal deformation. The fine granularity of the groundmass appears to indicate fairly rapid chilling to a solid state, probably accompanying the emplacement of the intrusive body. The surrounding rocks, however, were fairly hot, owing to their proximity to the volcanic throat, and further cooling of the intrusive mass therefore was slow. The intrusive remained for a considerable time at high temperature, during which time it recrystallized, acquiring in place of the original igneous texture a new one characteristic of crystallization in a solid medium. The instability of the rock at elevated temperatures probably was the result of the nature of the original groundmass pyroxene.

The pyroxene in the ejected blocks under discussion is unique among Kilauean lavas. The groundmass pyroxene in every other lava of Kilauea and Mauna Loa examined, in which its nature could be determined, is pigeonite. Hypersthene and augite are absent in the groundmass of Kilauean lavas, and hypersthene is rare even as a phenocryst, although phenocrysts of hypersthene are quite common in Mauna Loa lavas. The presence of hypersthene and augite in the groundmass of the ejected blocks requires, therefore, a special explanation. The explanation is not hard to find. It appears very probable that pigeonite in the groundmass of many basaltic rocks is meta-

stable at low temperatures,[6] and exists only because of the rapid cooling of the lavas containing it. Although in some instances pigeonite may form under plutonic conditions, on slow cooling,[7] such conditions generally result in the formation of two distinct phases, hypersthene and diopsidic augite.[8] When, therefore, the pigeonite-bearing rock was held at a high temperature for a long period of time, the pigeonite broke down and yielded hyperthene and augite.

[6] Bowen, N. L., and Schairer, J. F.: 1935, The system, MgO-FeO-SiO_2: Amer. Jour. Sci., 5th ser., vol. 29, pp. 153-217.

[7] Wager, L. R., and Deer, W. A.: 1939, The petrology of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland, Med. om Grønland, Komm. for Videnskabelige undersøgelser i Grønland, Bd. 105, nr. 4, pp. 240-261.

[8] Tsuboi, S.: 1932, On the course of crystallization of pyroxenes from rock magmas, Japanese Jour. of Geology and Geography, vol. 10, pp. 67-82.

HONOLULU, HAWAII.

(Contribution from the Sterling Chemistry Laboratory, Yale University.)

RADIOACTIVE SUBSTANCES. III.[1] THE ANALYSIS AND AGE OF A NORTH CAROLINA MONAZITE.[2]

ALLEN DOUGLASS BLISS.

ABSTRACT. A monazite from Spruce Pine, North Carolina, has been analyzed for thorium (4.83 per cent), uranium (0.02 per cent), and lead (0.18 per cent). The age as calculated by the customary formula is approximately 600 million years.

A STUDY of minerals collected recently in the Spruce Pine district of Mitchell County, North Carolina, made desirable the analysis for age determination of a monazite found in Deer Park No. 5 mine. Geological evidence indicates that the pegmatite in which this monazite occurs is younger than the Roan gneiss of Precambrian age.

The sample was a smooth-faced, prismatic, resinous-looking yellow stone weighing 20 g. For analysis it was wrapped in paper for breaking up with a hammer, crushed further in a clean "diamond" mortar, and finally ground to a powder in an agate mortar. One small piece was reserved for a density determination: 1.7261 g. ÷ (0.3322 ÷ 0.99612 (at 28.5°)) = density 5.18; monazites are reported[3] to have an average density of 5.2. The sample for the first thorium analysis was dried in an oven at 110° for half an hour and lost 0.025 per cent of its weight; the other sample weights were decreased by this amount in making the calculations.

The determinations of thorium, uranium, and lead were made according to the procedures recommended by Fenner,[4] with occasional minor variations as described in the Analytical Notes. The quantity of sample available did not permit using portions as large as advised in the procedures, and the weights taken

[1] Previous paper, Baxter and Bliss: 1930. *J. Am. Chem. Soc.*, 52, 4851.
[2] Presented at the Boston Meeting of the Mineralogical Society of America, December, 1941.
[3] Doelter, "Handbuch der Mineralogie."
[4] Fenner: 1928. Amer. Jour. Sci., 5th Ser., Vol. 16, 28, 868.

had to be decreased considerably. The reagents were distilled, recrystallized, or proved by appropriate tests to be free from the elements being determined.

ANALYTICAL NOTES.

Thorium (I).—Some difficulty was experienced in dissolving the first ignited oxides (*ex* oxalate) in sulfuric acid (with a few small losses by spattering); also, on standing, the first peroxynitrate filtrate deposited a small additional precipitate which was filtered and carried on separately to the final oxalate precipitation.

Thorium (II).—Guided by (I), the second analysis was executed more deftly, and deviated only in a repetition of the incident of a second small peroxynitrate precipitate, which was handled separately for a few stages and then combined.

Uranium (I).—On reaching the stage of the first ammonia precipitation, a mere trace of precipitate formed, indicating virtual absence of uranium. Following a suggestion of Dr. John P. Marble, the bulky precipitate from the potassium carbonate precipitation was processed to recover any included uranium. It was dissolved in hot nitric acid, diluted, rare earths precipitated with oxalic acid, digested, and filtered. The filtrate was evaporated with nitric acid (to destroy oxalate) to dryness, the solid dissolved in water, a trace of residue removed, and the solution alkalinized with ammonia to give a trace of *white* precipitate (again indicating practical absence of uranium). This small precipitate plus the one obtained in the regular procedure was extracted with hydrofluoric acid, the solution evaporated with sulfuric acid, diluted, cooled, and potassium ferrocyanide and sodium chloride added to give a trace of bluish precipitate which was filtered and washed with sodium chloride solution. The precipitate was leached with sodium hydroxide, then with hydrochloric acid, excess sodium carbonate added to the filtrate, boiled, a trace of iron filtered off, the solution acidified with hydrochloric acid, carbon dioxide boiled off, and excess ammonia added with boiling to give an almost invisible precipitate. Although the regular procedure involves further treatment, the trace of solid was filtered off, ignited, and weighed.

Lead (I).—This analysis was executed according to the suggested procedure, the final lead sulfate being dissolved out

of the crucible with hot ammonium acetate, any precipitate filtered, and washed, and paper with residue ignited in the crucible and weighed, its weight being used as the "empty" weight of the crucible.

Lead (II).—For this determination, all the residues of analyses Th (I), Th (II) and U (I) were saved. The various solutions were evaporated with nitric acid, then with sulfuric acid to fuming, and the residues dissolved and filtered, any undissolved material being treated again with sulfuric acid, until all was in solution with excess sulfuric acid. This solution was then analyzed by the usual procedure. Naturally it cannot be argued that all the lead content of these three original samples was recovered, but the close agreement of the two analyses is reassuring. The total yield of lead was recovered easily by precipitating it as sulfide from the final acetate extraction solution.

TABLE I.

Results of Analyses.

Analysis	Sample, g.	Precipitate, g.		%
Th(I)	1.9747	ThO_2	0.1080	Th 4.81
Th(II)	1.4524	ThO_2	.0803	Th 4.86
U(I)	3.8750	U_3O_8	.0008	U 0.017
Pb(I)	10.8867	$PbSO_4$[a]	.0205	Pb 0.129
Pb(II)[b]	7.3021	$PbSO_4$[a]	.0139	Pb 0.130

[a] The atomic weight of the lead was taken as 208.00 for calculations.
[b] The sample consisted of the combined residues of Th(I), Th(II) and U(I).

Commenting on the results, the difference of the thorium values is about as expected, in view of the protracted analytical work and the small amount of thorium oxide weighed. The figure for uranium is not a very tangible quantity; the 0.0008 g. weighed was a mere trace in the crucible, which might have been partially iron; a much larger sample would be needed to settle the question. The lead analyses show an agreeable concordance, in view of the even smaller yields of lead sulfate, and the composite nature of the second analysis. Fenner's procedures, however, have been tested repeatedly with satisfaction by various analysts, so these values would seem to warrant confidence.

Substitution in the well known equation

$$\frac{\text{Pb}\%}{\text{U}\% + 0.84\text{Th}\%} \times 7600 \text{ million years} = \text{age}$$

gives

$$\frac{0.1295}{0.0175 + (0.84 \times 4.888)} \times 7600 = 598 \text{ million years}$$

a value on the "older" side of the Cambrian period.

Acknowledgments.—The monazite specimen was collected by Prof. Adolph Knopf, and certain necessary items of equipment were loaned by the late Professor H. W. Foote, both of Yale University. Helpful advice on the uranium analysis was given by Dr. John P. Marble.

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A COMPARATIVE STUDY OF TWO CRETACEOUS VAGINULINAS.

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ABSTRACT. *Vaginulina wadei* Kelley and *V. webbervillensis* Carsey are studied as to distinguishing characteristics, stratigraphic position, and evolutionary relationship; and are found to be suitable index fossils for a part of the Upper Cretaceous.

THE genus *Vaginulina* is one of the most widely distributed and best developed of the many large and striking foraminifera in the Upper Cretaceous of the Gulf Coastal Region. The present study was undertaken in an attempt to distinguish clearly between two of the species of *Vaginulina* which superficially resemble each other, and, by a study of their stratigraphic distribution, to make them more useful for correlation purposes.

The writer acknowledges the courtesy of Dr. J. A. Cushman in making his laboratory, collections, and unpublished manuscripts available to her, and his helpful suggestions throughout this study.

VAGINULINA WADEI KELLEY.

Plate 1, Figs. 1-8.

Vaginulina wadei Kelley, in W. Berry and Kelley, Proc. U. S. Nat. Mus., vol. 76, Art. 19, 1929, p. 8, pl. 1, fig. 7.

Vaginulina webbervillensis Cushman (not Carsey), Tenn. Div. Geol., Bull. 41, 1931, p. 33, pl. 4, fig. 6.—Jennings, Bull. Amer. Pal., vol. 23, No. 78, 1936, p. 21, pl. 2, fig. 15.

Test large, elongate, compressed, broadest toward the apertural end, periphery usually carinate on the ventral edge, thickened and channelled on the dorsal edge, dorsal edge straight, ventral edge gradually tapering from the rounded proloculum; chambers as many as 25, distinct, increasing gradually in height and breadth as added, very slightly inflated toward the apertural end; sutures somewhat limbate but not raised, straight or very slightly curved backward as they approach the ventral edge; wall very finely perforate, with ornamentation varying from numerous, close-set branching costae over the entire test to a nearly smooth surface except for the costate proloculum and early portion of the test, the

costae being usually more strongly developed over the sutures and occasionally confined there; aperture at the dorsal angle, protruding, radiate.

Length up to 9.00 mm.; breadth of adult specimens, 1.20 to 2.00 mm.; thickness 0.40 to 0.55 mm.

This species, recorded as "very rare," was described from the Coon Creek tongue of the Ripley formation, Dave Weeks' place on Coon Creek, three and one-half miles S. of Enville, seven and one-half miles N. of Adamsville, and one-eighth of a mile E. of the main Henderson-Adamsville road, in the NE. part of McNairy County, Tennessee. The type specimen measured 1.88 mm. in length and is believed to be an immature specimen. An unpublished figure of the type, redrawn, shows more clearly than the type figure, the straight sutures, the thick intercameral walls, and the discontinuous costae.

Vaginulina wadei appears to be restricted to the Taylor group and the two lower members of the Navarro group: the Neylandville marl and the Nacatoch sand. Its greatest development, in size and abundance, is in the Marlbrook marl of southwestern Arkansas. Its areal distribution includes eastern Texas, southwestern Arkansas, northeastern Mississippi, western Tennessee, and New Jersey.

The following list of localities shows all the known occurrences of *Vaginulina wadei*, including the type locality, the localities from which it has been recorded by subsequent authors, and the localities represented by material in the Cushman Collection.

Taylor marl.

(Lower part) Bear Creek, 0.8 mi. S. by E. of Lavon, Collin Co., Texas. L. W. Stephenson.

(Lower part) On road to Little River and Temple, 8 mi. W. of Rogers, Bell Co., Texas. C. H. Dane.

(Wolfe City sand member) Road ditch, W. side of road, 1 mi. out of Wolfe City on road to Pecan Gap, Hunt Co., Texas. Cushman and Waters.

(Pecan Gap chalk member, basal part) On road to Lavon, Collin Co., 0.75 mi. W. of secondary road, 0.75 mi. N. of Rockwall, Rockwall Co., Texas. C. H. Dane.

Selma chalk.

(Mooreville tongue) From bed of gully, 40 feet below top of hill, Fulton road, 3/4 mi. W. of Mooreville, Lee Co., Miss. L. W. Stephenson. U.S.G.S. 9520.

(Middle part) Jim Wilkin's property, 300 yards NW. of Union Church, Hardin Co., Tenn. I. G. Reimann.

(Upper part) ½ mi. W. of Guys, McNairy Co., Tenn. I. G. Reimann.

Ripley formation.

Blue Cut, Mobile and Ohio RR. at state line, McNairy Co., Tenn. I. G. Reimann.

2½ mi. E. of Pontotoc, Pontotoc Co., Miss. G. W. Ponton.

(Coon Creek tongue) Dave Weeks' place on Coon Creek, 8½ mi. S. of Enville, 7½ mi. N. of Adamsville, and ⅛ mi. E. of the main Henderson-Adamsville road, in the NE. part of McNairy Co., Tenn. *V. wadei* was described from this locality.

Marlbrook marl.

(Upper contact) On highway 26, 6.5 mi. W. of corner of Tenth and Pine Streets in Arkadelphia, turn N. on country road to Cox place, sec. 29, T. 7 S., R. 20W, Clark Co., Ark. W. H. Deaderick.

Highway 51, 10.7 mi. SW. of junction with highway 26, at Tower No. 6, Unit 6, Arkansas Forestry Service, 3.0 mi. NE. of Okolona, Clark Co., Ark. W. H. Deaderick.

Natural erosion on E. side of road, highway 4, 3.8 mi. N. of Washington on road to Ozan, Hempstead Co., Ark. W. H. Deaderick.

¾ mi. NE. of Columbus, about ¼ mi. E. of road from Columbus to Yancey, Hempstead Co., Ark. W. H. Deaderick.

Tom Clark's Burns place. On highway 8, 4.0 mi. NW. of corner of Tenth and Pine Streets in Arkadelphia, turn N. at Trinity Church and 0.3 mi. further enter gate on left, Clark Co., Ark. W. H. Deaderick.

Saratoga formation.

Highway 26, about 150 yards W. of Wright's Store at junction with highway 51, Clark Co., Ark. W. H. Deaderick.

Highway 51, 0.7 mi. SW. of its junction with highway 26, natural erosion about 300 yards S. of road, Clark Co., Ark. W. H. Deaderick.

Neylandville marl.

S. side of U. S. highway 80, 2 feet above pavement, 12.5 mi. E. of Dallas-Kaufman county line, 0.6 mi. E. of Lawrence, Kaufman Co., Texas. C. G. Lalicker.

Nacatoch sand.

Ditch, 2nd class road, 1.7 mi. NE. of Ardis Heights, 3.5 mi. ENE. of Court House, Greenville, Hunt Co., Texas. L. W. Stephenson.

2 mi. S. of Oak Grove, Bowie Co., Texas. J. A. Gardner. U.S.G.S. 12982.

Mt. Laurel sand.

Nutt's Farm, on Crosswick's Creek, 0.6 mi. N. of New Egypt, Ocean Co., New Jersey. Recorded by Jennings.

Navesink marl.

Crawford's Corner, about 5 mi. S. of Keyport, New Jersey. Recorded by Jennings.

VAGINULINA WEBBERVILLENSIS CARSEY.

Plate 1, Figs. 9-18.

Vaginulina webbervillensis Carsey, Univ. Texas Bull. 2612, 1926, p. 89, pl. 2, fig. 7.—Cushman, Contr. Cushman Lab. Foram. Res., vol. 6, 1930, p. 27, pl. 4, fig. 14.—Plummer, Univ. Texas Bull. 3101, 1931, p. 160.—Cushman, Special Publ. No. 5, Cushman Lab. Foram. Res., 1933, pl. 20, fig. 12.—Cushman and Todd, Contr., vol. 19, 1943, p. 59, pl. 10, fig. 21.

Test large, compressed, broadest toward the apertural end, dorsal edge nearly straight, thickened, tricarinate, ventral edge curved, sometimes undulating; proloculum costate and with a distinct spine; chambers as many as 25, distinct, of about equal height throughout, last-formed ones sometimes slightly inflated; sutures distinct, becoming limbate toward the dorsal edge and almost invisible toward the ventral edge, nearly straight in the early portion, becoming strongly curved backward in the adult test so that the ventral portions of the sutures are almost parallel with the ventral edge of the test; wall smooth, very finely perforate, sometimes ornamented along the ventral edge with a few curved, discontinuous costae most strongly developed toward the initial end; aperture at the dorsal angle, protruding, radiate.

Length up to 7.5 mm.; breadth of adult specimens, 1.50 to 3.00 mm.; thickness 0.50 to 0.60 mm.

The type locality of this species was not designated in the original description, but was subsequently stated by Mrs. Plummer (Univ. Texas Bull. 3101, 1931, p. 121) to be the strata exposed in a steep 80-foot slope on the right bank of Onion Creek just east of the bridge (known as Jones' Crossing) on the Austin-Bastrop highway, Travis Co., Texas.

The original description gives the length as "up to 6 mm., but more commonly about 4 mm.," and the species was recorded as "rather common in some parts of this formation" [Navarro].

Vaginulina webbervillensis appears to be restricted to the upper beds of Navarro age: Corsicana marl, Kemp clay, Arkadelphia marl, and Prairie Bluff chalk. Its areal distribution includes a north-south belt in eastern Texas extending from Bexar to Hunt counties, southwestern Arkansas, northeastern Mississippi, and southern Alabama.

Vaginulina webbervillensis occurs at the following localities represented by material in the Cushman Collection:

Prairie Bluff chalk.

Houston road, in a shallow gully W. of road near foot of large hackberry tree about 10 feet below top of chalk in nearby road cut, 1.4 mi. N. by E. of Sparta, Chickasaw Co., Miss. L. W. Stephenson and W. H. Monroe. U.S.G.S. 17285.

Houston road, in road cut about 8 feet below top of section, 7.4 mi. N. by E. of Sparta, Chickasaw Co., Miss. L. W. Stephenson and W. H. Monroe.

17 feet down N-facing slope of Cane Creek valley in sec. 10, T. 15 S., R. 8 E., 1.8 mi. N. by E. of Sparta, Chickasaw Co., Miss. W. H. Monroe.

Old Canton Landing, Alabama River, Wilcox Co., Ala. U.S.G.S. 6439.

Arkadelphia marl.

Branch E. of road, ½ mi. N. by W. of Reed's Store (SW. ¼ sec. 29, T. 11 S., R. 24 W.) 6 mi. N. by W. of Hope, Hempstead Co., Ark. L. W. Stephenson.

(Lower part) 4.5 mi. E. of Washington, in creek ½ mi. N. of Reed's Store, Hempstead Co., Ark. U.S.G.S. 8211.

(Near base) 7 mi. N. by W. of Hope, Hempstead Co., Ark. L. W. Stephenson. U.S.G.S. 18411.

Corsicana marl.

Small branch below road 2½ mi. N. of Tona siding, about 5 mi. SW. of Quinlan, Hunt Co., Texas. L. W. Stephenson.

Pit at Corsicana Brick Co. 2 mi. S. of Court House at Corsicana, Navarro Co., Texas. L. W. Stephenson.

(Within 1 foot of top of Corsicana marl) Road ditch, 3.5 mi. NW. of Union Seminary School, 4.3 mi. SSE. of Corbet, Navarro Co., Texas. L. W. Stephenson.

Mexia highway at forks of Wortham road, 2.8 mi. ESE. of Cooledge, Limestone Co., Texas. Cushman and Thomas.

Mexia road, 2¾ mi. E. of Cooledge on E-facing slope of Elm Creek valley, Limestone Co., Texas. L. W. Stephenson and C. H. Dane.

Ditch, W-facing slope of Big Creek valley, 8 mi. SW of Stranger, 1.8 mi. SE. of Parsons Bridge, Falls Co., Texas. L. W. Stephenson.

Bluff on Onion Creek, 1/4 mi. below Bastrop road crossing, 2¼ mi. W. of Old Garfield, Travis Co., Texas. L. W. Stephenson.

Steep 80-foot slope on right bank of Onion Creek just E. of bridge (known as Jones' Crossing) on the Austin-Bastrop highway, Travis Co., Texas. *V. webbervillensis* was described from this locality.

Gully in W-facing slope of Cottonwood Creek valley, 1/4 mi. W. of Kimbro, 2 mi. S. of Manda, Travis Co., Texas. L. W. Stephenson. U.S.G.S. 14129.

San Marcos River, left bank, 100 yards below a ford, ½ mi. below Martindale, Caldwell Co., Texas. L. W. Stephenson. U.S.G.S. 7621.

8 feet below base of *Exogyra-Gryphaea* bed, San Antonio road, 6 mi. E. of Castroville, Bexar Co., Texas. L. W. Stephenson.

Kemp clay.

(Upper part) Branch ½ mi. S. of McLeod School, 6½ mi. SW. of Curry, Navarro Co., Texas. L. W. Stephenson.

90 feet below base of Midway group, Wortham road, 5 mi. due E. of Cooledge, Limestone Co., Texas. L. W. Stephenson.

Mustang Creek, about 6 mi. ESE. of Taylor, Williamson Co., Texas. L. W. Stephenson and W. P. Popenoe.

Sandy marl, 6 to 8 feet above bottom of pit of Seguin Brick and Tile Co., 0.8 mi. S. of McQueeney Station, Guadalupe Co., Texas. L. W. Stephenson.

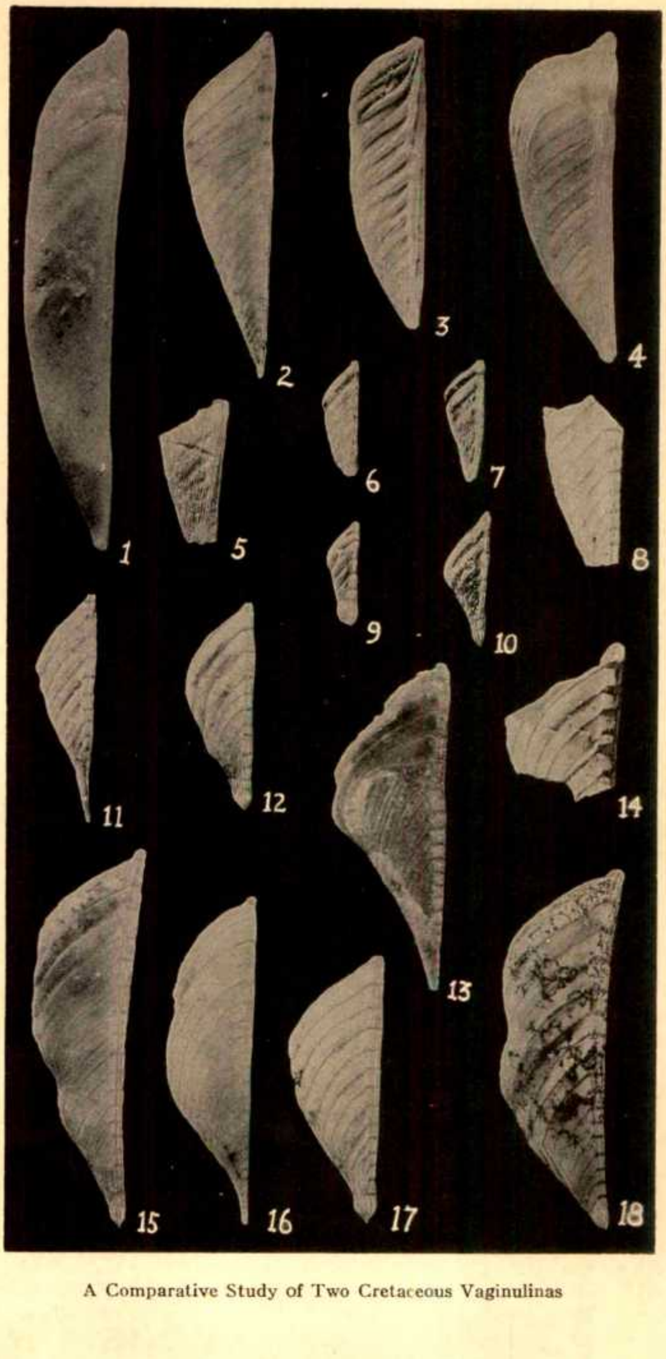
There is one record for *V. webbervillensis* in the Eagle Ford shale (Moreman, Journ. Pal., vol. 1, 1927, p. 98, pl. 16, fig. 2).

EXPLANATION OF PLATE 1.

All figures x 8.

Figures 1-8. *Vaginulina wadei* Kelley. Marlbrook marl (upper contact), on highway 26, 6.5 mi. W. of corner of Tenth and Pine Streets in Arkadelphia, turn N. on country road to Cox place, sec. 29, T. 7 S., R. 20 W., Clark Co., Ark. 1, Megalospheric, narrow form. 2, Microspheric form. 3, Megalospheric form showing ornamentation. 4, Megalospheric, broad form. 5, Fragment showing extremely fine and dense costae. 6, 7, Young forms. 8, Fragment showing straightness of sutures.

Figures 9-18. *Vaginulina webbervillensis* Carsey. 9-12, 14, 15, 17, 18, Mexia highway at forks of Wortham road, 2.8 mi. ESE. of Cooledge, Limestone Co., Texas. 13, 80 feet above base of bluff on Onion Creek, 2½ mi. W. of Old Garfield, Travis Co., Texas. 16, about 17 feet above base of bluff on Onion Creek. 9-12, Young forms. 11, 13, 16, Microspheric forms. 13, Broken and repaired test. 14, Fragment showing curvature of sutures. 15, 17, 18, Megalospheric forms.



A Comparative Study of Two Cretaceous Vaginulinas

Mrs. Plummer stated (Univ. Texas Bull. 3101, 1931, p. 160) that she had examined the plesiotype and found it "to conform well to many of the variations that characterize the species at any locality in the Navarro where it is abundant." Nevertheless, in view of the fact that there are no other records for this species in either the Taylor or Austin groups, some doubt must remain as to the authenticity of this earlier record.

REPAIR OF BROKEN TESTS.

During the examination of specimens in this study a considerable number of tests which had been broken and repaired were observed. Two of these are figured (Figs. 2 and 13). In Fig. 2 the test was broken at a point about 1/3 the length from the apertural end where there is a slight jog in the dorsal edge. From this point to the aperture there are 4 chambers, the first of which truncates 2 of the previous ones. Fig. 13 shows a specimen which seems to have lost a much greater proportion of its test as the break truncates 5 of the previous chambers and the rebuilt chambers are about twice the height of the broken-off ones as well as much longer as they curve around the broken-off edges. This increase in size of the rebuilt chambers suggests that as the animal grew something in the living protoplasm determined the size of chamber to be built regardless of the size of the immediately preceding chamber. From this assumption one might judge how large the test had been before the break and how much was missing due to the break.

DISTINGUISHING CHARACTERISTICS.

The most striking difference between *Vaginulina webbervillensis* and *V. wadei* is the presence of an initial spine on *webbervillensis* and its absence on *wadei*. In the over 600 specimens examined, no cases were found where both forms, with and without spines, were found in the same sample.

The shape of the test, especially of the early part, may be used as a distinguishing characteristic. In *V. webbervillensis* the test broadens much more rapidly than in *V. wadei* and the ventral edge is curved or undulating. In *V. wadei* the test broadens gradually and evenly so that the ventral edge is almost as straight as the dorsal, and is frequently angled at the point where the last-formed chamber reaches the ventral periphery.

When only small fragments are available (such as Figs. 8 and 14) it is usually possible to distinguish between the two species on the basis of sutures. In *V. wadei* they are straight almost to the ventral periphery while in *V. webbervillensis* they become distinctly curved as they approach the ventral periphery.

In ornamentation the two species differ chiefly in degree. *V. webbervillensis* has the costae usually confined to the periphery and the first few chambers. In *V. wadei* the costae appear commonly, but not always, over the entire surface of the test.

POSSIBLE EVOLUTIONARY CONNECTION.

From a study of young specimens, it became evident that the general appearance of *V. wadei* (i.e., straight sutures and straight ventral periphery with an angle where the last-formed chamber meets it) is repeated in the young specimens of *V. webbervillensis* (See Figs. 6, 7, 9, 10). This ontogenetic relationship suggests that the later species developed from the earlier one.

There does not seem to be any noticeable difference between specimens of *V. webbervillensis* from the four different formations in which it occurs. *V. wadei*, on the other hand, becomes larger, more robust, and somewhat broader in the younger formations in which it occurs. It is largest and most abundant in the Marlbrook marl; but in the Navarro group, especially the Nacatoch sand, it approaches *V. webbervillensis* in its curved sutures and proportionately broader and smoother form. On the basis of fragments these Nacatoch specimens probably could not be distinguished from *V. webbervillensis*. However, all specimens showing the initial end are rounded and without a spine, and on this basis are considered to be true *V. wadei.*

Thus two lines of evidence suggest that *V. webbervillensis* may have developed from *V. wadei* through the curving of the sutures, broadening of the test, loss of some surface ornamentation, and the development of an initial spine. These two lines of evidence are: first, that young specimens of *V. webbervillensis* resemble adult specimens of *V. wadei* except in size and initial spine: and second, that specimens of *V. wadei* which are nearest to *V. webbervillensis* in age are nearest to them in their characteristics.

CONCLUSIONS.

The two species of *Vaginulina* may be distinguished by the following features: presence of initial spine of *webbervillensis*; shape of test, broad in *webbervillensis* and narrow in *wadei*; straightness of sutures in *wadei* and curvature in *webbervillensis*; and degree of ornamentation greater in *wadei* than in *webbervillensis*. The wide occurrence of both species in strata where the other is not known makes them suitable for index fossils; *V. wadei* being restricted to beds of the Taylor group and the lower beds of the Navarro group, and *V. webbervillensis* being restricted to the upper beds of the Navarro group.

CUSHMAN LABORATORY,
SHARON, MASS.

DISCUSSION.

CARLISLE CENTER FORMATION, A NEW NAME FOR THE SHARON SPRINGS FORMATION OF GOLDRING AND FLOWER.

Goldring and Flower (Amer. Jour. Sci., 1942, vol. 240, p. 677) proposed the Sharon Springs formation for strata lying between the Esopus shale as restricted and the Schoharie grit in New York. Dr. M. K. Elias (fide litt.) has pointed out that this name was previously used by him for a member of the Cretaceous Pierre shale as developed in Kansas and Colorado. (See Wilmarth, 1938, vol. 2, p. 1969.) Therefore the new name *Carlisle Center formation* is proposed by Goldring and Flower for their Sharon Springs formation.

WINIFRED GOLDRING AND R. H. FLOWER.

Albany, N. Y.
Bryn Mawr, Penna.

SCIENTIFIC INTELLIGENCE

PHYSICS.

Hydrogen Ions; by HUBERT T. S. BRITTON, Vol. I and Vol. II. Third edition. Pp. xix, 420. Pp. xix, 448; many illustrations. New York, 1948 (D. Van Nostrand Co., $16.00).—The present edition of this work is an enlargement of the second edition. The book has the character of an uncritical summary of a considerable part of the experimental and theoretical work in the field of water solutions of electrolytes. The emphasis is laid on manifestations of hydrogen ion equilibria. Much detailed discussion of experimental matter is included. Old and new work is presented side by side. The reader unfamiliar with the subject might well become confused in an attempt to plan an experiment on the basis of material here presented.

Approximately half of the first volume is taken up with discussions of experimental methods. Various hydrogen electrodes and the instruments used in the measurements are described. Chapters on volumetric analysis and the standardization of volumetric solutions form a transition to a group of four chapters on theoretical matters. It seems somewhat unfortunate that the highly developed and rigorous thermodynamic theory of solutions of electrolytes should be presented as if it were nearly on a par with an hypothesis in need of experimental test. The chapter on "activity theory" ends with a two page discussion of the correct basis for a definition of pH. The author concludes that for practical purposes the pH should be defined by the method used in its determination: i.e., by means of the e. m. f. of a cell with transference standardized against the normal hydrogen electrode in which the conductance ratio is used to compute the hydrogen ion concentration. A short chapter on the Lowry-Brönsted theory of acids and bases precedes a summary of the composition of various buffer solutions. The remainder of the first volume is taken up with discussions of colorimetric pH determinations and the use of indicators in titrations.

Approximately half of Volume II is devoted to the significance of pH in various fields of chemistry. Redox reactions, titrations in non-aqueous solvents, precipitations of various classes of inorganic compounds are discussed. Much experimental work is here summarized. The final eighteen chapters discuss the significance of pH in various industrial processes and for various natural products. Electrodeposition of metals, tanning, sugar, pulp and paper, beer, milk, hen's eggs, cheese, bread, water, soils, ceramics, the dye industry, and ore flotation all receive attention. The final chapter is entitled "Miscellaneous."

If this book be accepted in its character of a literature survey it may prove useful to those interested in the field.

HENRY C. THOMAS.

Infrared Spectroscopy. Industrial Applications and Bibliography; by R. BOWLING BARNES, ROBERT C. GORE, URNER LIDDEL, and VAN ZANDT WILLIAMS. (Reinhold Publishing Corp., New York, 1944, $2.25).—This little book is a reprint of a paper which appeared in *Industrial and Engineering Chemistry* (*Analytical Edition*), Volume 15, No. 11, pages 659 to 709, by Barnes, Liddel, and Williams. It is an excellent discussion of the various aspects of the application of the methods of infrared spectroscopy to chemical problems. The "library" of 868 representative spectra of organic compounds should prove invaluable to those working in this field. In addition a bibliography of 2,701 references in the field is included. The bibliography is arranged alphabetically according to authors' names and is indexed according to subject matter. While the bibliography makes no claim to completeness, much of the library chore of anyone planning an infrared investigation is done for him herewith. HENRY C. THOMAS.

GEOLOGY.

Geologia do Brasil; by AVELINO IGNACIO DE OLIVEIRA and OTHON HENRY LEONARDOS. Servico de Informacao Agricola, Série Didática N. 2, Pp. XVII+813, Second edition, 202 text figures, 273 plates, 1 colored map. Rio de Janeiro, 1943. (Price about $8.00).—The authors of this imposing work have earned the gratitude of geologists everywhere in bringing together in a single volume a comprehensive and up-to-date summary of all that is known of the geology of Brazil.

Chapter 1 reviews the history of geologic work in Brazil from the beginning of the nineteenth century to 1943. Succeeding chapters treat of the geology from the point of view of historical geology, Chapter 2 being devoted to general features of the Archeozoic, Chapter 3 to the Archean, Chapter 4 to the Algonkian, Chapter 5 to general features of the Paleozoic era, Chapter 6 to the Cambrian, Chapter 7 to the Ordovician, etc.

Each chapter devoted to a distinct geologic period begins with general features, such as paleogeography, climate, and distinctive types of life, and then proceeds to treat in detail of the geology of each important area of outcrop. Seventy-one half-tone plates show characteristic geologic views, and 202 plates of fossils reproduce approximately all the published figures of invertebrate fossils and some of the fossil vertebrates and plants of Brazil. The large number of text figures show detailed maps or stratigraphic and structure sections. The large, colored geologic map is on the scale of 1:7,000,000. CARL O. DUNBAR.

The United States Exploring Expedition, 1838-1842, and its Publications, 1844-1874: A Bibliography; by DANIEL C. HASKELL, with an Introductory Note by HARRY MILLER LYDENBERG. Pp. XII+188; 5 plates. New York, 1942 (The New York Public Library).—On August 18, 1838, Lieut. Charles Wilkes sailed from Norfolk in charge of a squadron of five small naval vessels on one of the most pretentious scientific expeditions ever undertaken by the United States government.

At that time about ten per cent of the ships flying the *Stars and Stripes* were engaged in the whaling industry, much of it in the South Pacific. That region was still little known to the scientific world—even the continent Antarctica was yet to be discovered! With the great economic importance of whaling in the South Seas, it became a matter of public concern to know more about the natural history of that remote region, and so the Congress had commissioned Lieutenant Wilkes to conduct "a surveying and exploring expedition to the Pacific Ocean and the South Seas."

After four adventurous and exciting years, three of the ships returned laden with collections and data which were to form the basis of no less than 24 volumes of scientific reports. Study of the biological materials was entrusted to the foremost American scientists of the day—such men as Louis Agassiz, James D. Dana, Asa Gray, and Spencer F. Baird—and some of their reports are now classics.

But, from the first, the scientific work was plagued by political interference and mismanagement. The expedition had been authorized by Congress and organized by the Navy Department but its objectives had to be attained by civilian scientists. Bitter friction over organization and equipment had delayed the expedition for two years before it sailed; and upon its return the Congress, having to appropriate money for the study and publications of the scientific data, tried to control the character and volume of the scientific reports and the style and conditions of their publication. The inevitable result of such an impossible organization was controversy and delay and charges and recriminations, and an almost incredibly tangled bibliography, which is the subject of the present volume.

Early estimates of the time needed, and the volume of publication required, had to be revised upward as the vast collections were studied, and Wilkes had to battle with Congress year after year for additional appropriations. At the start the politically-minded Congress arranged for publication of the scientific results on a purely political basis—only 100 copies were to be printed, one to be presented to each state in the Union and the rest to be distributed to foreign countries through the State Department! The scientists concerned protested bitterly at such a limited edition as would make

their works virtually "forbidden fruit" to nearly all the scientific world. Eventually, after much controversy, authors were permitted to arrange privately for publication of additional copies of their works and so all of the volumes eventually appeared in unofficial issues differing slightly from the original official issues.

The present volume by Mr. Haskell reviews all this tangled history, gives a full bibliography of the publications of the expedition, as well as of books and periodical articles relating to the expedition and its results, and a list of manuscripts prepared but never published. It also includes a checklist of the holdings of these publications by the libraries of the world. CARL O. DUNBAR.

PUBLICATIONS RECENTLY RECEIVED.

Kansas Geological Survey. Bulletin 52. Pt. I. Reconnaissance of Pleistocene Deposits in North-Central Kansas; by C. W. Hibbard, J. C. Frye and A. B. Leonard. Pt. II. Ground-Water Conditions in the Neosho River Valley in the Vicinity of Parson, Kansas; by C. C. Williams, Lawrence, 1944.

U. S. Geological Survey: 102 Topographical Maps; Map of Spokane River. Plan and profile of Spokane River, Spokane, Wash., to Post Falls, Idaho; topography by G. C. Giles and Washington Water Power Co. Scale, 1:12,000. 4 sheets (8 plans, 1 profile). (Prepared in cooperation with the State of Washington.)

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THE DISTRIBUTION OF HELIUM AND RADIOACTIVITY IN ROCKS.

VI. THE AYER GRANITE-MIGMATITE AT CHELMSFORD, MASS.

N. B. KEEVIL, E. S. LARSEN, AND F. J. WANK.

ABSTRACT.—Of twelve minerals studied in concentrates from the Chelmsford granite-migmatite, zircon, apatite, epidote, and biotite have more than five times the radioactivity of the parent rock; accessory minerals account for half the total radioactivity. A 150,000-fold contrast in helium content was found between zircon and feldspar, yet the zircon containing 1.2 cc./g. appears to retain helium, while more than ninety per cent has escaped from feldspar and quartz. Excess helium over that produced since Carboniferous time was found in sphene.

RECENT radioactivity studies of rocks have shown appreciable contrasts between the constituent minerals, mafic minerals tending to be about three times as active as felsic and certain of the accessory minerals to be considerably more active than either of these groups.[1] In a California tonalite, for example, zircon, sphene, and apatite were 1030, 680, and 140 times as radioactive as biotite, itself generally regarded as a relatively radioactive mineral.[2] While such minerals have long keen known to be radioactive from early experiments on minerals, zircon-rich rocks,[3] concentrates, and so forth, it was by no means certain that weakly radioactive rocks containing little or no visible zircon and apatite would show such contrasts in radioactivity. The Californian tonalite contains only 0.06 per cent zircon and sphene and has an activity of only 0.8 alpha rays/mg./hr. and a radium content of 4.9×10^{-13} grams per gram.

The granite-migmatite at Chelmsford, Massachusetts, on the other hand, is relatively radioactive, having a radium content of 53×10^{-13} g./g. and an activity ten times that of the Californian tonalite. In order to find whether greater contrasts in radioactivity between the constituent minerals exist in the

Chelmsford rock, minerals were separated from two typical facies at the Fletcher Quarry near North Chelmsford, Massachusetts. At the same time determinations of the helium index were made on all of the samples, in order to find which minerals were the best reservoirs for the helium produced by radioactive disintegration at a nearly uniform rate during geological time.

DESCRIPTION OF GRANITE-MIGMATITE.

The Fletcher quarry from which the specimens were taken is in one of the central bodies of several detached areas of granitic rock lying in a belt extending from Hempstead, New Hampshire, through Worcester, Massachusetts, to Connecticut. Sometimes referred to as an outlying part of the great central batholith of New England, the rock is not now considered to be of the granite batholith type, but to be a hybrid rock formed by granitization at depth of earlier sediments and schists.[4] Such hydro-magmatic invasion is suggested by the uniformity of the biotite banding, the orientation of inclusions, and the distribution of the masses which conform with the regional schistosity and structure of the biotite schist. In thin section, the three generations of feldspar are not zoned but often exhibit corrosion contacts, and many evidences of metasomatic processes are discernible.

The time of granitization is generally believed to be late Carboniferous. In the Worcester and Merrimac troughs biotite and muscovite granitic rocks, presumably of the same age and origin, intrude strata identified as Carboniferous by the presence of fossil trees and ferns of the "Calamites" and "Lepidodendron" types. The granites cut the Worcester phyllite and all other solid rocks of the area, except the diabase dikes. The latter are similar to those interbedded with Triassic sediments at Mount Holyoke, Mount Tom, and Deerfield, Massachusetts.[5] The geological information, though indirect, suggests that the age of the migmatite is 250 ± 50 million years.[6]

Macroscopically the medium-grained Chelmsford "granite" is light-colored, being composed chiefly of white feldspar with some quartz, brown biotite, and occasional garnets. In the thin section of sample CG, 40 per cent microcline, 20 per cent oligoclase, 30 per cent quartz, and less than 10 per cent biotite and muscovite were estimated to be present (Table I). Accessories consist of apatite, zircon, clinozoisite, and epidote.

Some sericitization and chloritization has taken place. Light colored feldspathic pegmatite dikes associated with the granite contain appreciable muscovite and garnet. In thin section, the minerals in specimen CP exhibit considerable evidence of strain. Fractured microcline with quartz veinlets, and rounded fractured grains of garnet associated with muscovite were observed. Coarse grains and fine aggregates of quartz and muscovite were present, and a few rare grains of zircon were identified.

Currier[4] believes the order of formation of the minerals during granitization to have been as follows:

TABLE I.

Composition of Specimens of Chelmsford Migmatite.

	(Percentages)			
Mineral	Coarse	Medium-grain	Fine	Pegmatite
Quartz	35	30	33	25
Microline	20	40	28	65
Plagioclase	40	20	32	..
Muscovite	5	..	5	8
Biotite and chlorite	0.5	..	0.7	..
Epidote	..	..	1.1	..
Magnetite	..	..	0.02	..
Apatite	..	..	0.001	..
Zircon	..	..	0.001	..
Sphene	..	..	0.001	..
Garnet	..	..	0.005	2

1. Original schist-biotite, and smaller amount of quartz, feldspar, carbonate, garnet, and minor minerals.
2. Development of soda-lime feldspar, oligoclase, etc.
3. Microcline and muscovite porphyroblasts.
4. Albitization.
5. Hydrothermal development of quartz, epidote, apatite, zircon, sphene, chlorite, subordinate feldspar, and late tourmaline-bearing veins.

It should be noted, however, that while some tiny crystals of zircon were observed, pleochroic halos around zircon grains in biotite suggest that some of the zircon may have been present in the biotite schist and formed prior to granitization.

EXPERIMENTAL DATA.

The procedures used in separating the minerals have been described previously.[2] For the fine-grained granite 1700 g.

were ground to 1 mm., some less. Compositions of the final samples used for helium and radioactivity investigations were as follows:

Sample	
1	Fine-grained granite-migmatite.
2	Biotite, partly altered to chlorite.
3	Larger crystals of biotite; hand picked.
4	Muscovite; hand picked.
5	Muscovite, 95%, quartz and feldspar, 4%, biotite and chlorite, 1%.
6	Quartz, 60%, plagioclose, 37%, orthoclase, 3%, chlorite, trace.
7	Orthoclase, 95%, quartz and plagioclase, 5%.
8	(Magnetic) Chlorite, 48%, biotite, 41%, feldspar, 6%, epidote, 2%, sericite, 2%, muscovite, 1%.
8a	Sericite, epidote, and feldspar, 65%, muscovite, 28%, quartz and feldspar, 5%, biotite and chlorite, 2%.
8b	Feldspar, sericite and epidote, 49%, muscovite, 49%, apatite, 2%.
9	Magnetite and ilmenite, 68%, mixed quartz, feldspar, and sericite, 15%, garnet, 10%, apatite, 5%, biotite, chlorite and muscovite, 2%, mineral x (brown, nearly opaque, birefracting).
9b	Epidote, 68%, mixed epidote, feldspar and sericite, 28%, zircon, 2%, garnet, 1%, sphene, 1%.
9c	Sphene, 30%, muscovite, 30%, quartz and feldspar, 20%, mixed sericite, feldspar, chlorite, etc., 15%, epidote, 5%.
11	Garnet near border of fine aplite dike, garnet, 95%, quartz and feldspar, 5%.
12	Coarse-grained granite-migmatite.
13	Hand picked, coarse muscovite.
13a	Hand picked, finely crystalline muscovite.
14	Muscovite, 30%, sericite, 25%, quartz and feldspar, 25%, epidote, 20%.
15	Quartz, 65%, plagioclase, (Ab_{85} An_{15}), 35%.
16	Plagioclase, 60%, quartz, 40%.
17	Microcline, 96%, quartz and plagioclase, 4%.

Helium and radioactivity determinations have been made on all of these samples, and also on other samples of granite and pegmatite. The experimental results are given in Table II.

At first glance it may appear that the results on minerals are uncertain due to the necessity of studying impure samples. Actually, however, it is possible to obtain good probable values for most of the minerals. Zircon, for instance, in sample 9b, obviously determines the high helium content and high activity even though it is present to the extent of only 2 per cent; and corrections for the other constituents, though minor, can readily be made using average values determined for relatively pure samples of microcline, biotite, muscovite and garnet. Quartz and plagioclase can be grouped together because of apparently little difference between the two, and their effects as impurities are small. It is reasonably certain that the

TABLE II.

Experimental Data for Chelmsford Granitic Rocks and Associated Minerals.

Number of Sample	Essential Constituents	Helium Content $\times 10^{5}$cc./g.	Activity Alphas/ mg./hr.	Helium Index 30.7 He/a
1	Fine-grained migmatite	5.55	6.15	28
6	Quartz and plagioclase	1.85	1.17	48.5
7	Microcline	1.47	1.31	34.5
4	Muscovite (hand picked)	1.2	1.365	27
5	Muscovite (heavy liquid)	7.26	9.46	24
3	Biotite (hand picked)	33.4	13.1	78
2	Biotite with chlorite	7.53	22.24	10.3
8	Biotite, chlorite, epidote	29.2	21.9	43
8a	Muscovite, epidote, felsics	37.9	43.2	27
8b	Epidote, apatite, felsics	375	52.8	218
9	Apatite, magnetite, ilmenite, garnet, felsics	265	45.2	180
9b	Zircon, epidote, felsics	2540	423	184
9c	Sphene, epidote, muscovite, felsics, and chlorite	265	19.5	418
CG	Medium-grained migmatite	16.8	7.82	66
CP	Asociated pegmatite	0.58	0.78	23
12	Coarse-grained migmatite	5.78	5.76	30.5
15	Quartz and plagioclase	0.47	1.66	9
16	Plagioclase and quartz	0.95	1.72	17
17	Microcline	0.13	2.52	1.6
13	Muscovite (hand picked)	1.61	8.64	5.7
13a	Muscovite (fine)	1.49	1.49	30.7
14	Epidote, felsics	88.5	45.0	60
11	Garnet (near border of aplite dike)	38	3.47	336

activity of sericite is comparable with feldspar from which it may have been derived during alteration, and by comparison with the related mineral muscovite a low value for sericite is also suggested. This consideration leads to a probable value for epidote by using the data in samples 8a and 14. The only other assumption that has to be made is that magnetite has an average retentivity[6] of 0.7, and that the activity is comparable to that which it exhibits in other moderately active granitic rocks:

Paleozoic granite, Buchans, Nfld.	12.7
Granite N. of Fort Rae, N.W.T.	14.0
Average	13.3

With these two assumptions it is a simple matter to determine the activity and helium contents for all the constituent minerals.

The values calculated in this way, and given in Table III, are believed to be fairly reliable. The orders of magnitude are consistent with recent results, and are self-consistent within themselves. For example, the values in Table III may be used to calculate the helium contents and activities of any of the mineral mixtures studied, with excellent agreement between calculated and experimental values. The only exception is sample 8b, and here the presence of 0.00020 per cent zircon would account exactly for the discrepancy, both in the helium content and in the radioactivity.

TABLE III.

Radioactivities and Helium Data for Chelmsford Minerals.

Mineral	Helium x 10^5 cc./g.	Activity Alphas/ mg./hr.	Helium Index	Helium Retentivity[1]	Source of data Sample Nos.
Microcline	0.8	1.9	18	0.05	7, 17
Quartz and plagioclase ...	1.1	1.5	23	0.09	6, 15, 16
Muscovite	1.48	1.5	29	0.12	4, (13), 13a
Biotite	33.4	13.1	78	0.31	8
Chlorite	1.1	24.5	1.4	0.006	3; sample 2
Magnetic chlorite	6.6	11.3	18	0.07	taken as 20% biotite
Magnetite	70	13	....	....	assumed value[2]
Epidote	320	213	46	0.18	8a, 14
Garnet	40.3	8.58	340	1.36	11
Apatite	4260	710	185	0.74	9, (8b)
Zircon	120,000	14,000	260	1.03	9b
Sphene	248	8	955	3.82	9c

[1] Assuming age to be 250 M.y.

[2] From average of active magnetites in granitic rocks, and average helium retentivity of magnetite, see ref. 6.

In the case of the rock the percentages of the accessories (which are important in the present connection) are only known approximately, and an estimation of the exact composition of the granulated samples used in the experiment was not attempted. Therefore the agreement between calculation and experiment, while not exact, is also considered quite satisfactory (Table IV).

TABLE IV.

Contributions of Mineral Constituents to Radioactivity of Chelmsford Granite-Migmatite.

Minerals in order of increasing activity	Per cent of rock	Helium in 1 g. of rock x 10^{-6}cc./g.	Activity in 1 g. of rock Alphas/mg./hr.	Contribution of Mineral to activity of rock per cent
Muscovite	5	0.07	0.08	1.9
Quartz and plagioclase	65	0.72	1.00	23.4
Microcline	28	0.22	0.54	12.6
Garnet	0.1	0.04	0.00	
Sphene	0.001	0.02	0.00	
Magnetite	0.02	0.01	0.00	
Biotite and chlorite	0.7	0.05	0.16	3.7
Epidote	1.1	8.52	2.34	54.8
Apatite	0.001	0.04	0.01	0.2
Zircon	0.001	1.20	0.14	3.4
Granite (fine) ..	100	5.9 (calc.)	4.3 (calc.)	100
Granite (fine)		5.55 (exp.)	5.5 (exp.)	
Granite (coarse).		5.78 (exp.)	5.76 (exp.)	

DISTRIBUTION OF RADIOACTIVITY.

The distribution of radioactivity roughly parallels that observed in the Californian Lakeview tonalite[2] and that suggested by other studies.[1, 4]

	Chelmsford	Lakeview
Zircon	14,000	401
Apatite	710	56
Sphene	8	266
Epidote	218	..
Biotite	25	0.4

The chief differences are the low activity indicated for sphene in the Chelmsford migmatite, and the high activity indicated for epidote in this rock. Epidote is one of the minerals formed during the late hydrothermal stage of the granitization process, as are all of the active minerals in the Chelmsford migmatite; this suggests that the late hydrothermal fluids were relatively highly radioactive. Quartz and sphene separating in these later stages, may be low due to the phase equilibrium laws governing their separation in this particular case.

The specific activity of zircon is by far the highest yet found for minerals separated from the normal range of granitic rocks. The activity of 14,000 corresponds approximately to a thorium content of 0.08 g./g. and a radium content of 7×10^{-9} g./g.

RELATIVE RETENTION OF HELIUM.

The minerals giving a helium index close to the expected age of 250 M.y. are apatite and zircon, this in spite of their high activities and correspondingly high rates of helium production. Zircon, for example, contains 1.2 cc. of helium per gram. This is a remarkable quantity to have been retained during geological time, not only because of the escaping pressure that such a concentration of helium would exert, but also because of the partial disruption of the zircon crystal caused by the radioactive distintegration that produced the helium. However, occasional high apparent retentivities of some dense radioactive minerals have been noted elsewhere, and it has been shown in a theoretical treatment of "helium and interatomic forces in rocks" that close-packed structures of unaltered minerals should be able to retain helium during geologic time.[7] The results for garnet are only a little higher than the expected age. The difficulty in applying such encouraging results to age determination is the apparent unpredictability of the results. Zircon in the Californian tonalite, for example, has a helium retentivity of only 0.2 instead of 1. Aside from sphene, and to some extent, garnet, the retentivities for helium shown by the other minerals are of the order expected from previous work,[6] but somewhat lower; felsic minerals and those with cleavage are now known to be of no use in determining age by the helium method.

EXTRANEOUS HELIUM.

Helium nearly four times in excess of that expected through radioactive decay within sphene was found, and a small amount of extraneous helium in garnet is also indicated. While the data for sphene were obtained indirectly, considerations of the experimental data for sample 9c show definitely that some extraneous helium is present. As in the case of the magnetite and ilmenite concentrate from Yellowknife, North West Territory,[8] excess helium is associated with a titaniferous mineral. The helium may have been formed by earlier radioactive pro-

cesses not evident at the present time, or else helium may have been trapped during crystallization from the hydrothermal fluid. Another possible explanation in the present case is that garnet and sphene from the biotite-schist host rocks may not have been completely recrystallized during granitization; in any case, considerable helium from the older rocks would be evolved during the process of hydro-magmatic invasion, which may be partially trapped during recrystallization.

SUMMARY.

(1) More than twenty samples of rock and mineral concentrates from the Chelmsford granite-migmatite have been studied.

(2) A wide range of radioactivities was found for twelve mineral constituents; a 10,000-fold contrast in activity and a 150,000-fold contrast in helium content in zircon and feldspar were found.

(3) Over half the activity of the Chelmsford granite is due to accessory minerals.

(4) Zircon and apatite contain nearly the expected helium for a Carboniferous rock, the former containing 1.2 cc. of helium per gram.

(5) As expected, feldspars, micas, and alteration products exhibit low retentive properties.

(6) Considerable excess helium is indicated to occur in sphene and a small excess in garnet, derived possibly from that produced in the host-rocks prior to granitization.

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A UNIQUE TOPOGRAPHIC EXPRESSION.

ROLAND BLANCHARD.

ABSTRACT. In Diamond Valley, central Nevada, the author some years ago noted that ponds of sodium sulfate consistently have the greatest thickness of cakes, and highest peripherally ridged-up soil borders, at the north ends of the ponds. Gentle northward slope of the terrain probably accounts in large part for the condition, but the phenomenon persists locally also upon level or very gently southward-sloping terrain. A possible additional explanation to cover the latter cases is offered. Further suggestions to account for the phenomenon would be welcomed.

PREFACE.

IN 1922 the author examined a sodium sulfate deposit in central Nevada, situated in Diamond Valley 25 to 30 miles northeasterly from Eureka. Exploitation of the deposit was not proceeded with at the time, and the incident passed from his mind. Recently the notes made by him have come to light. The author has not been in America since 1929 and has no knowledge of what may have taken place at the deposit since then, but his notes emphasize a topographic feature so unique that he feels its description may be of interest to other geologists.

OCCURRENCE OF THE SODIUM SULFATE.

The sodium sulfate occurs in disconnected ponds near the edge of a broad flat valley, about four miles from the nearest foothills. The elevation is aproximately 6000 feet. When inspected by the author in 1922 the ponds ranged in size from less than 20 feet across to irregular shapes up to 1600 feet in maximum dimension. They lay in two main groups or clusters several miles apart, each group being contained mostly within an area one mile square. In the respective groups the larger ponds rarely were separated from one another by more than 1000 feet. The ponds were basin-shaped, nowhere extending laterally beneath the valley wash. The wash itself consisted of a loose, sandy desert soil into which the foot might sink from one-fourth to one inch when walking, but which nevertheless carried an appreciable intermixture of fine clay particles.

In appearance the sodium sulfate was crystalline and translucent, resembling bluish-white ice. It was exceptionally pure, free of iron, nearly free of sodium carbonate and clay, contain-

ing usually not more than 0.75 per cent NaCl. The clay washed out readily.

Within a given pond the sulfate occurred both as large, solid masses and as irregular cakes of varying size; only in the smaller ponds were unbroken surfaces observed. The largest measured cake was estimated to contain 65,000 tons dry Na_2SO_4. It averaged 45 inches thick, but locally was much thinner, and at one place exceeded 70 inches in thickness. More frequently there was present an aggregation of cakes which individually did not exceed 100 to 200 feet in maximum dimension. The largest single pond was estimated to contain more than 100,000 tons dry Na_2SO_4.

The time of inspection was August, when the earth probably had absorbed its maximum of summer heat. The sulfate cakes, not quite submerged, floated in a matrix of watery mud composed of desert soil saturated with sodium sulfate solution, which worked upward between and around the cakes, and locally overflowed onto and coated them with two to ten inches of a soft, white pasty ooze, so that mud and ooze combined constituted variably 20 per cent to 40 per cent of the total pond surface. No layers of sodium sulfate were encountered beneath the floating cakes while testing the latter with jumper drills at coördinate intersections, but in the underlying ooze crystals of sulfate three to four inches long were studded thickly and promiscuously through it, decreasing and finally virtually ceasing with depth as the ooze merged into thick mud three to six feet beneath the cakes.

Whether the deposits represent old lake beds was not established. The ponds were not interconnected; they were localized as isolated shallow depressions in the sandy soil upon a flat, gently northward-sloping valley floor which did not at that place constitute a specific drainage basin or a readily detectable, generally depressed area of the landscape. In testing with the jumper drills, numerous vents were tapped beneath the larger cakes from which issued strong bubbling columns of H_2S. Old residents at the nearby Cox ranch stated that entirely new ponds more than 100 feet across had formed within their memories, and that smaller ponds sprang up in new places perennially without visible diminution in size or depth of adjoining ones. Although it was not proved, there seemed no reason for thinking that the deposits might not now be forming in much the same manner as bog iron deposits are forming in cur-

rent geologic time. Crystallization of the sulfate from the underlying ooze in any event was taking place, because holes put through the cakes during the day filled with the watery fluid from beneath, which invariably crystallized out in part as sodium sulfate before morning. The amount of sulfate increased notably with coldness of the night. This is in accord with the sodium sulfate-water solubility curve given in Figure 1, which shows that the solubility reaches its maximum at 33° C. (91.4° F), and decreases rapidly with drop in temperature.

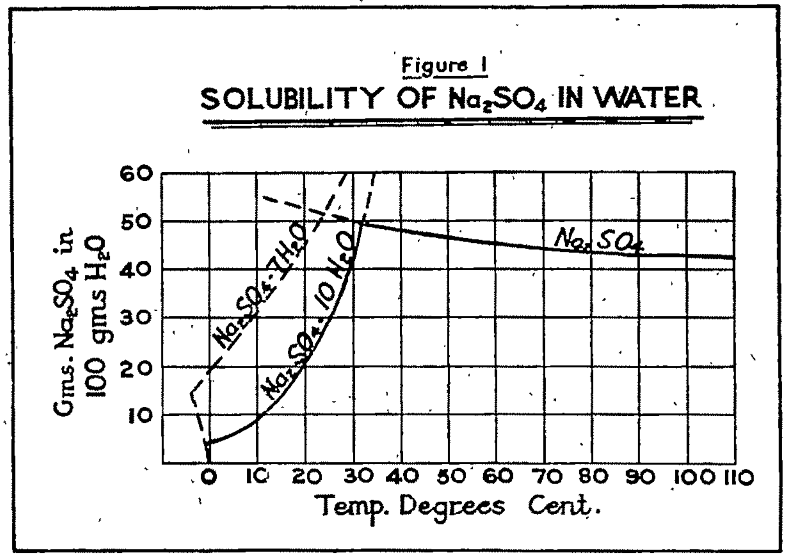

Fig. 1.

According to Fig. 1 (assuming no extraneous factors intervened) 81.7 per cent of the sodium sulfate in saturated solution at 33° C. would crystallize out through a drop in temperature to 10° C. (50° F.), the normal temperature range between mid-afternoon and dawn during the summer months. Between 33° C. and 0° C. (32° F.), 90 per cent of the sodium sulfate in solution would crystallize out. Temperature variations between the warm days and cool nights of the desert summer at that latitude and altitude, and in a larger way between the warm summers and cold winters, thus would keep up a more or less perpetual precipitation of the sodium sulfate so long as the solution continued in supply.

UNIQUE FEATURES OF THE DEPOSITS.

Whether representing old lake beds or current deposits formed as suggested above, the occurrences in Diamond Valley, as described, are not essentially different from sodium sulfate deposits elsewhere, except possibly for their purity. But two features relating to them are unique: 1, without exception, large or small, the crystallized sulfate cakes are thickest in the northern half of the ponds. For example, a cake that at the south end of a small pond might average ten inches thick, would average probably 18 to 20 inches thick at the north end; in a larger pond having correspondingly larger cakes, the thickness might be two to three feet at the south end and five to six feet at the north; 2, at the borders of the ponds, particularly around the larger ones, the soil is ridged up from two to eight feet above the valley floor. The bordering ridges mostly slope steeply on their inner sides, toward the ponds, and grade off almost imperceptibly, on their outer sides, into the valley floor. Similarly, without exception, they are conspicuously higher at the northern than at the southern ends of the ponds: if the soil and sand is ridged up, say, one foot above surface of the pond at the south end, it is ridged up two to three feet at the north end; or, for the larger ponds, the corresponding figures might be three feet at the south end and six to eight feet at the north. The condition is illustrated in Fig. 2. No ridge was

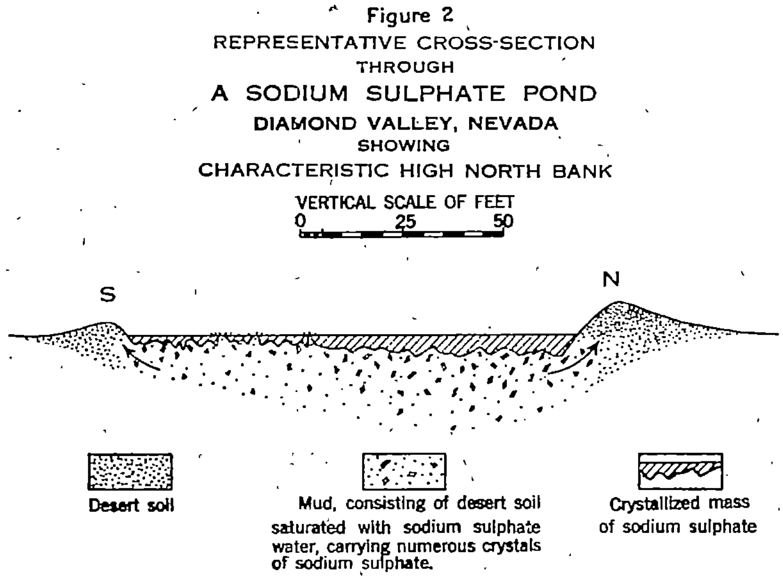

Fig. 2.

seen that exceeds seven to eight feet in height, presumably because the desert wind readily shifts dry, loose soil and sand that overtops the general level of the sagebrush and other low desert vegetation.

SUGGESTED EXPLANATIONS.

Riding upward of the soil around borders of the ponds is not difficult to explain: during the summer the cakes floated in the soft mud or ooze, and as by accretion they grew in size and weight they isostatically displaced the soft fluid beneath. This fluid oozed upward between the cakes and in part spread over them within the ponds as already explained, but tended more to escape around edges of the cake aggregates, resulting in formation of the peripheral ridges as the displaced ooze and mud dried. Development of the steeper slopes and greater elevation of the ridges on their inner sides, toward the ponds, would be the natural outcome, because immediately at the pond peripheries the displaced mud fluid would meet with less resistance in its upward surge than it would farther outward. Inspection of Fig. 2 makes this clear.

The explanation does not, however, account for the invariably greater thickness of the sulfate cakes, and invariably greater height of the ridges, at the north ends of the ponds.

The sand dune theory has been advanced to explain the consistently greater ridge heights at the north ends, but it fails because (1) the ridge pattern, with its steep inner and flat outer slope, is as marked at the south, east, and west as along north ends of the ponds; (2) sand dunes that have formed in more distinctly sandy areas elsewhere in Diamond Valley do not conform with the sulfate pond pattern described.

With the topography sloping gently northward, any sulfate solution issuing at the surface would meet initial obstruction to its flow by a clump of sagebrush or whatever other soil emergence lay in its path, and would tend to pond on the south side thereof. Through growth it would expand in time into one of the larger ponds, slowly but steadily ridging up the soil around its borders. Water in the pond would seek its level, and with northward-sloping terrain the pond's greatest depth necessarily would be at its north end, with consequent increased thickness of cakes at that end. Isostatic adjustment inevitably would result, under such conditions, in displacement upward of more soil around the northern periphery of the pond than elsewhere.

The explanation is simple, and is adequate for most cases. But not all of the ponds lay along locally northward-sloping terrain, though the general slope was in that direction. Transit surveys made at the time of inspection revealed that in numerous instances the surface is essentially level, and in one notable case slopes southward at $\frac{1}{2}°$ for a pond nearly 200 feet long; yet little if any measurable disparity could be detected between relative thickness of the cakes, or heights of peripheral borders, at the respective north and south ends in these instances, as compared with ponds of corresponding size where the terrain slopes gently northward. For example, in case of the $\frac{1}{2}°$ southward-sloping terrain seven holes through the cake at the south end of the 200-foot pond averaged 13 inches deep; seven holes placed in corresponding positions at the north end averaged $23\frac{1}{2}$ inches deep. The bordering ridge at the south end rises to an average height of 16 inches above the pond; at the north end, to an average height of 37 inches. Even where the terrain slopes gently northward the thickness of cakes at the north ends of the ponds in more than one instance was greater than could be accounted for solely on the basis of topographic slope.

Manifestly, some causative factor has been operating independently of or in addition to the northward slope of the terrain.

A possible explanation may lie in the fact that at the latitude of central Nevada (39° to 40° N.) the sun always shines from the south. Greater heat absorption and radiation thus would occur on the south slopes of obstructions, with consequent higher solubility of sodium sulfate during the day in solutions at the north ends of the ponds. Tests made with a thermometer showed that, in mid-afternoon for ponds that exceed 20 feet across, surface temperatures of the watery fluid at the north ends ranged from 3° to 8° F. higher than at the south ends, the discrepancies rising with amount of dark soil ridged along borders of the water's surface. On the other hand, as result of the cool desert nights, watery surfaces of the ponds wherever tested at dawn were of uniform temperature at any point along their peripheries.

Preferential solar heat absorption and radiation along the north borders of the ponds thus may have been an important and possibly vital factor in development of the Diamond Valley phenomenon where the terrain is level or where locally it slopes

DETERMINING FACTORS IN THE COLORATION OF GRANITE SOILS IN THE SOUTHEASTERN PIEDMONT.

WILLIAM A. WHITE.

ABSTRACT. Through its control of internal drainage, jointing also controls the alternation of oxidizing and reducing conditions in the soil. Red soils develop on closely jointed granites because they have good internal drainage and oxidizing conditions prevail in them. Yellow soils develop on sparsely jointed granites because they have poor internal drainage and reducing conditions prevail in them during a large share of the time.

THE determining factors involved in the genesis of the several types of residual soil which commonly develop on the granites and granite gneisses of the southeastern states have posed somewhat of a problem to geologists and soils scientists working in that region. Among such factors those which produce the differences in color have been the most difficult to explain, and it is with them that this paper is concerned.

In general, granite soils may be divided into two color groups; such series as Cecil and Surry being red while Appling, Durham, and Louisburg are yellow or yellow with gray topsoils. The determining factors in the development of the several soils in each of these two color groups is largely a matter of topographic position, drainage and similar factors which have been generally recognized, but the reason why the soils of one group are colored red by ferric oxide while those of the other are colored yellow by ferrous oxide has remained inscrutable. Frequently a single rock body without showing any perceptible difference in lithological character will be overlain by a patchwork of red and yellow soils which show no apparent rhyme or reason in their distribution. Furthermore, both red and yellow soils can be found on a number of different granitic rocks which are quite variable in mineralogical composition, particularly in so far as their iron-bearing accessory minerals are concerned.

Field evidence observed by the writer suggests that frequency of jointing in the underlying rock is the deciding factor in determining the color of the soils. Through its effect upon

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internal drainage the jointing appears to control the extent of oxidation and consequently the color of the iron compounds. In areas of intimately jointed rock, percolation is facilitated by the interconnecting joints, and weathering is accelerated by the resulting alternation of wet and dry conditions. In dry periods the joints are occupied by air, and during wet periods they serve as arterial avenues for the downward movement of rain water carrying oxygen in solution. After the rain water has passed down to the permanent water table a fresh supply of air enters the joints replacing that which was displaced by the water. Continuing repetition of this process creates an environment conducive to deep weathering and complete oxidation. The iron is converted to the ferric form coloring the soil red.

In unjointed rock masses, on the other hand, downward movement of rain water is restricted to intergranular cracks and other minute and discontinuous openings. Consequently, deep percolation is restricted or absent and the zone of saturation remains near the surface for longer periods of time after rains. This lag in drainage is augmented by the fact that mature, yellow soils usually occur on areas of low relief and therefore have somewhat poor horizontal drainage along the bedrock surface. During such prolonged wet periods reducing conditions prevail and partially negate the tendency toward oxidation. Consequently the iron adopts the lower oxide or ferrous form and colors the soil yellow.

Innumerable observations in road cuts have attested the validity of assigning the red color to soils developed upon intimately jointed rocks. The yellow soils are best seen in relation to their parent rocks in the many granite quarries of the region. Dimension-stone quarries are characteristically surrounded by yellow soils demonstrating the relationship between unjointed rock masses and yellow soils.

Road cuts showing bedrock are more numerous in areas of red soils than in areas of yellow ones. However, this is a further argument for the relationship between closely spaced jointing and red soils. The Piedmont is a slightly dissected plateau with largely subsequent drainage. Dissection has apparently followed zones of more closely spaced joints and road cuts are of course more common in such dissected areas than in the undissected divide areas.

The large flat areas mantled by the Durham and Appling series (the more highly developed of the yellow soils) appear on

the undissected peneplane remnants; a fact which suggests that such areas have superior resistance to dissection because of the unfractured rock which underlies them.

In this connection it is interesting to note that young granite soils such as the Louisburg series usually grade laterally into soils of the yellow group, and yellow soils form the dominant cover around granite monadnocks. They invariably surround erosional domes such as Stone Mountain in Georgia and its many smaller counterparts throughout the Piedmont of Georgia and the Carolinas. The unjointed character of such granite and gneissic domes is a patent fact.

If the conclusions reached in this paper are true, they should provide a valuable aid in the search for ground water in the southeastern granite areas, for the red soils should furnish a guide to the fractured areas where successful drilled wells may be located in bed rock.

An attempt was made to correlate soil types with production data from drilled wells but very little classifiable data could be obtained. It may be said, however, that the scanty records available tend to confirm the thesis of this paper. Those wells which had been drilled into granites underlying yellow soils had generally proven failures while those in granites underlying red soils usually gave satisfactory production.

Further evidence for the unjointed nature of the rocks underlying yellow soils may be found in the fact that water tables characteristically stand higher in them and they remain wet for longer periods following rains.

The bulk of the writer's observations have been made in areas of granite and definite conclusions apply only to granite soils, but it is quite possible that further investigation may discover similar relationships between soil color and jointing in other rocks. In the case of the "Carolina slates" which are largely metamorphosed acid tuffs and lavas there is some reason to believe that the relation between jointing and soil color is similar to that of the granites; the red soils developing upon fractured rock; the yellow soils on unfractured.

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ON ROUNDED PEBBLES.[1]

H. C. COOKE.

DURING the field work of 1943, the writer observed in the bed of Salmon River, eastern Quebec, a number of reddish pebbles. Examined, these proved to be of brick; and all were well rounded (Fig. 1). It was evident that if the history of these pebbles could be traced, they might yield quantitative data on the conditions required for rounding.

Salmon River, a tributary of St. Francis River, runs north through the eastern part of the Scotstown quadrangle, longitude 71° to 71° 30′, north latitude 45° 30′ to 45° 45′, in the Eastern Townships of Quebec. Scotstown, a small manufacturing center, is situated on the river near the south boundary of the quadrangle. At Scotstown the river is 90 feet wide, and in low water has an average depth of 12 to 18 inches; in times

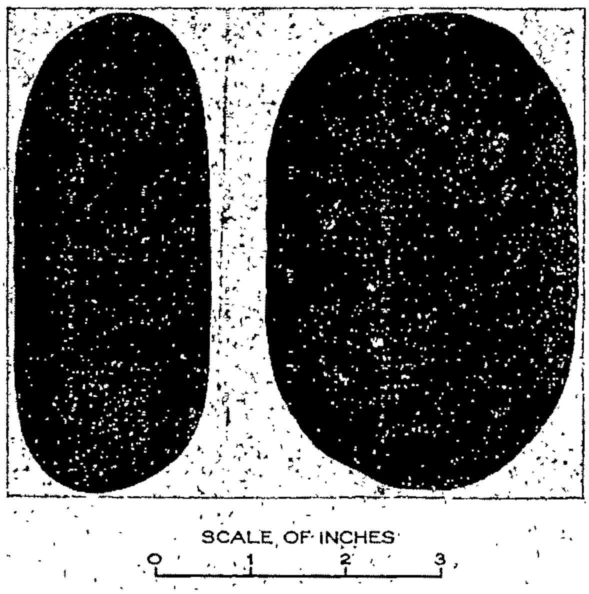

Fig. 1. Side and Front views of rounded brick pebble from bed of Salmon River, half a mile below Scotstown, Quebec.

[1] Published with the permission of the Director, Mines & Geology Branch, Department of Mines & Resources, Ottawa.

of flood the depth may attain 6 feet, or even more. Below the village the river is one long rapid for about two miles, with a fall approximately of 40 feet per mile. The pebbles were observed almost exactly half a mile below the bridge at the village.

The pebbles are fairly numerous, hence must have had some source of abundant supply. As the village houses, with one or two recent exceptions, are all of frame construction, except of course for the chimneys, this rules out the possibility of the fragments being tossed in the water by small boys.

Just above the present bridge is a boiler-house built of brick at some time prior to 1910; and at first sight it seemed as if the brick fragments under discussion had most probably fallen into the river during its construction. Further inquiry, however, ruled out this possibility also.

According to Mr. John Taylor, one of the oldest inhabitants, a short distance below the present bridge there was a concrete dam, above which a lumber company built a brick stack on the shore of the river, some 60 years ago. After some 15 years, the company ceased operations, and the stack was wrecked and allowed to fall on the bank; and the bricks were sold to persons needing them for building. Some 20 or 25 years ago, according to Taylor, there was a big flood, so high that the water flowed around the ends of the dam and cut deep channels. Taylor stated that 16-foot logs were carried through these channels, on end; but making all allowances for pardonable exaggeration, it is not difficult to believe that the ground was gullied to perhaps 7 or 8 feet. The flood appears to have carried away the remnants of the stack.

Taylor's story was corroborated by the manager of the Guelph Cask Veneer and Plywood Company. According to him, the flood occurred at some time after he returned from the Great War in 1919. It washed out a bridge maintained by that company at or near the dam; and the bridge was replaced the following year. Reference to the books of the company showed no mention of the expense of replacement in 1923 or later; as further investigation would have required digging out older books from the vault, the writer did not press it. Obviously, however, the bridge must have been replaced not later than 1922, so that the flood must have taken place in 1921 or one of the two previous years—22 to 24 years ago.

The concrete dam mentioned was maintained by the local electric light company till 1926 or 1927. At that time power was brought in from a distance, and the need for its production locally ceased. The dam was thereupon destroyed.

This dam would certainly have barred the passage of brick fragments as long as it existed, except during the big flood; and, as mentioned, the flood also seems to have carried into the river the remains of the old stack. If the inferences are correct, then thorough rounding of the fragments occurred in less than 25 years, in the course of a movement of slightly less than half a mile downstream.

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THE CHILHOWEE GROUP AND OCOEE SERIES OF THE SOUTHERN APPALACHIANS.

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PART I

CONTENTS.

ABSTRACT. The Chilhowee group and Ocoee series of the Southern Appalachians are defined, their formations are listed, and their distribution and structural relations are briefly described. Published reports covering the area described are reviewed and discussed, and the confusion which has arisen from the misuse of formation names and the errors in age determination of the rocks are pointed out. The problem of the correlation of the formations of the Chilhowee group with other Lower Cambrian formations is discussed. Evidence is presented to show that the Ocoee series is not Cambrian, as heretofore believed, and that its formations are not equivalent to Cambrian formations of the Chilhowee group; that the Ocoee series is of late pre-Cambrian age; that it is equivalent in age to the following late pre-Cambrian rocks:—Mount Rogers volcanic series in southern Virginia and northern Tennessee and North Carolina; the Lynchburg gneiss in Virginia and North Carolina; Fauquier formation and Catoctin basalt in northern Virginia; Swift Run tuff and Catoctin basalt in northern Virginia and Maryland; Talladega series in Alabama and Georgia.

INTRODUCTION.

A WIDE belt of quartzose sedimentary rocks forms the northwest border of the Appalachian Mountains from Holston, Cherokee, and Buffalo Mountains, Tennessee, southwestward across Tennessee and North Carolina into Georgia, and lies southeast of the Great Valley. The quartzose rocks

are in part Lower Cambrian in age and in part pre-Cambrian. They were mapped in Tennessee before 1869 by Safford,[1] and later were mapped and described in North Carolina, Tennessee, and Georgia in eight geologic folios of the U. S. Geological Survey and in other reports of the Federal and State Surveys. In these reports the age designation and the correlation of the stratigraphic units of these quartzose rocks vary greatly. This paper is an attempt to clarify the stratigraphy and to rectify some of the errors of correlation contained in previous reports, and is not intended as a criticism of the work of geologists who have previously studied the region.

FIELD WORK IN THE AREA.

This paper is based on data from published geologic maps and from manuscript maps on file in the U. S. Geological Survey and on field work by the writers. In 1898 the senior author studied and mapped a small area in the northwestern part of the Mount Guyot quadrangle for the U. S. Geological Survey. During the first World War he studied part of the belt in connection with manganese investigations. In 1930-31 both writers made a field study of the belt during a reconnaissance of the Southern Appalachians from Virginia to Alabama in the preparation of the geological map of the United States for the U. S. Geological Survey, which was published in 1933. During the last ten years a large part of the writers' field work has been in the Appalachian Mountains of southern Virginia for the Virginia Geological Survey. They have made a geological survey of the Blue Ridge Parkway in Virginia and North Carolina for the U. S. Park Service, and have done further detailed field work in the northeastern part of Tennessee and North Carolina for the purpose of extending southwestward the stratigraphy and structure which they had worked out in detail in southern Virginia.

ORIGINAL DEFINITION OF ROCK UNITS.

Safford[2] divided the quartoze rocks of southeastern Tennessee into three divisions. The rocks in the northwestern part of the belt he called Chilhowee sandstone, and later Chilhowee

[1]Safford, J. M.: 1856, A geological reconnaissance of Tennessee, First Biennial Report of State Geologist, pp. 151-152; 1869, Geology of Tennessee, Rept. of the State Geologist, p. 158.

[2]Safford, J. M.: idem.

series, of Lower Cambrian age. In this paper these rocks will be called the Chilhowee group. The rocks that form the larger part of the belt Safford called the Ocoee series of Eozoic age. On the southeast side of the Ocoee series he described the metamorphic group, in which are included rocks that he referred to the Ocoee series and granite gneiss, which he believed to be probably older than the Ocoee series (p. 177).

Safford's[8] type section of the Ocoee series is along the narrows of the Ocoee River in southeastern Tennessee. He described the Ocoee rocks as coarse, dark conglomerate and dark slates of semi-metamorphic aspect, and said that the dark color, the coarseness of conglomerate, the predominance of slate, and the metamorphic character of the Ocoee series are the basis of separation from the Chilhowee group, which is characterized by sandstone and white quartzite. On his map of 1869, Safford showed the Ocoee series as extending from the southwestern part of the Roan Mountain quadrangle along the mountain belt of southeastern Tennessee to the Georgia state line, south of Ocoee River.

GENERAL DESCRIPTION.

Fig. 1 shows the extent of the area of quartzose rocks described in this paper and Safford's division of these rocks in Tennessee into the Chilhowee group, Ocoee series, and metamorphic rocks, as given on his map of 1869. Except in certain places in the northeastern part of the area, the writers agree with Safford's mapping. Fig. 1 shows also the name, number, and author of the published geologic folios and the name and location of quadrangles that have been mapped in preliminary form but have not been published.

Fig. 2 shows the extent of the Ocoee series and the Chilhowee group based on previous work of others and the interpretation by the writers. The belt of Ocoee rocks begins at the north at a point southwest of Buffalo Mountain in the Roan Mountain quadrangle and extends southwestward into Georgia, to and beyond Cartersville. The rocks in the western part of the belt are stratigraphically continuous from the northeastern end to the gorge of the Ocoee River, Tennessee, which is the type locality of the Ocoee series. The northwest border of the Ocoee series is a great thrust fault on which the Ocoee series

[8] Safford, J. M.: 1856, Op. cit. pp. 151-152; 1869, pp. 183-189.

has ridden northwestward over the Lower Cambrian Chilhowee group and younger Paleozoic rocks of the Great Valley. In the area extending from southern Tennessee to Cartersville, Georgia, Hayes[4] named the bounding fault the Cartersville thrust. At a much later date Keith[5] named this fault in south-

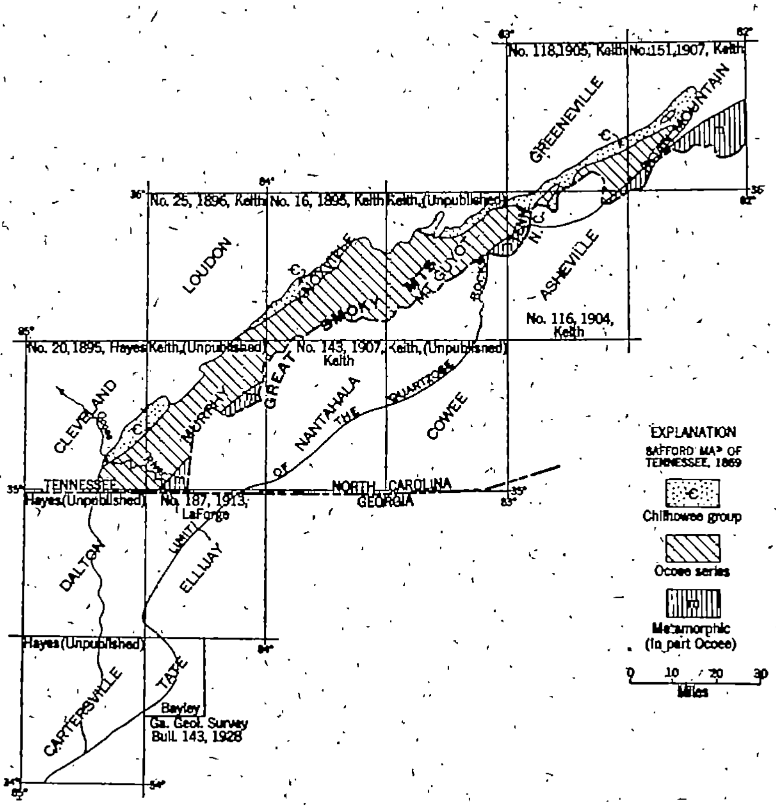

Fig. 1. Index map of the Southern Appalachian Mountains, showing quadrangle names and authors of reports. It shows also the extent of the quartzose rocks described in this paper and the distribution of the Ocoee series in Tennessee as mapped by J. W. Safford, 1869.

ern Tennessee the Great Smoky overthrust. The southeast boundary of the belt of the Ocoee series is in large part an overthrust, on which equivalent and older rocks have ridden northwestward over the Ocoee series. In northern Georgia and

[4] Hayes, C. W.: 1891, Overthrust faults of the Appalachians: Geol. Soc. Amer. Bull., Vol. 2, pp. 147-149.

[5] Keith, Arthur: 1927, The Great Smoky overthrust, abstract: Geol. Soc. Amer. Bull., Vol. 38, pp. 154-155.

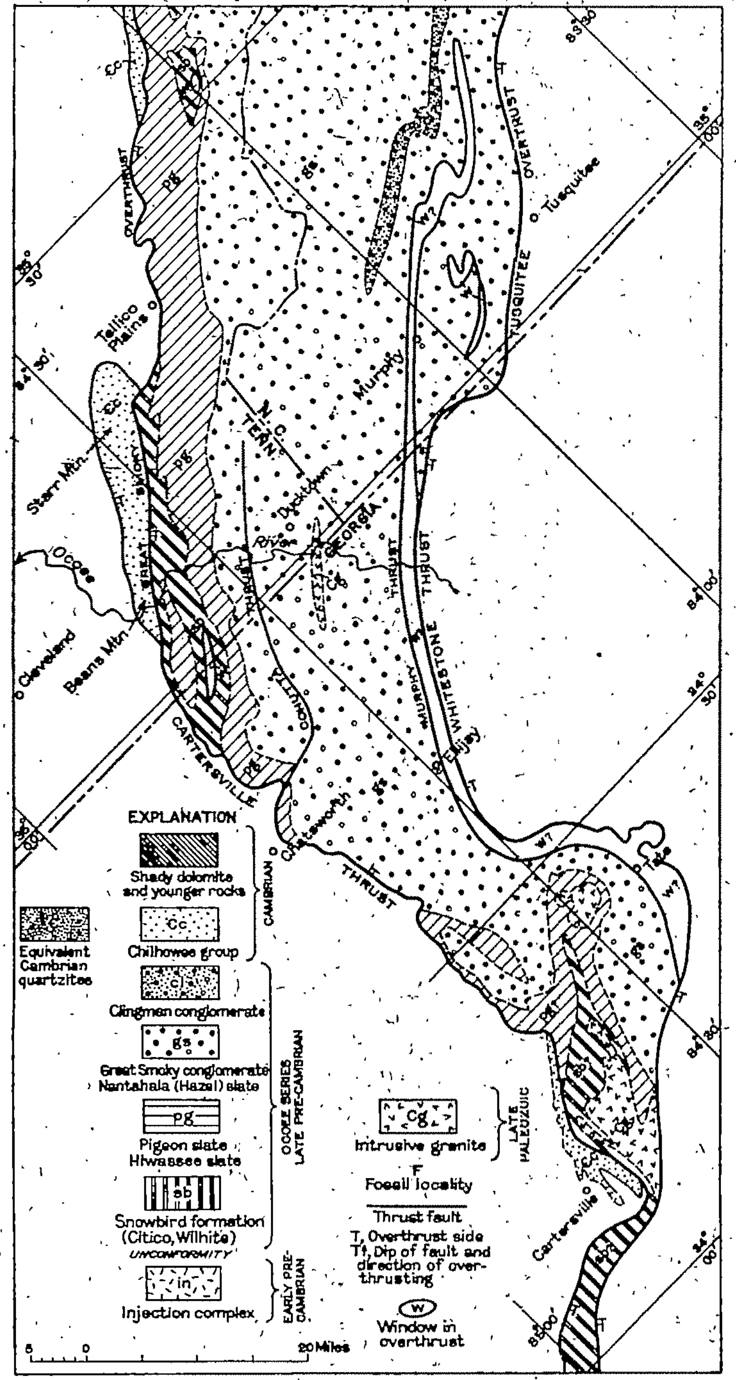

Fig. 2A. Map of the Ocoee series and Chilhowee group in Tennessee, North Carolina, and Georgia. The mapping of the subdivisions of the Ocoee series is based on the maps of Keith and others as interpreted by G. W. and A. J. Stose.

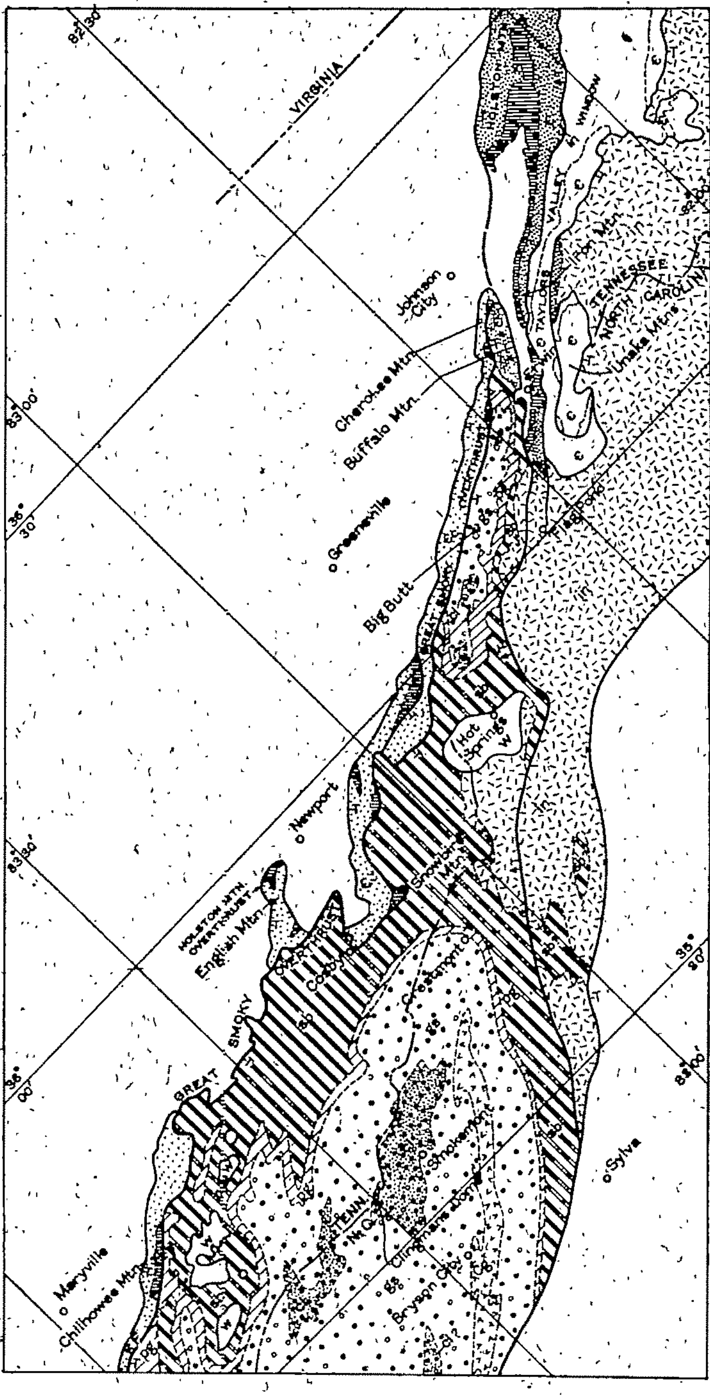

Fig. 2B. Map of Ocoee Series and Chilhowee group.

southern North Carolina La Forge and Phalen[6] named this fault the Tusquitee overthrust, and the writers here use the name Tusquitee for the extension of the fault northeastward and southwestward from the place where it was named. The age and stratigraphic relation of the Ocoee series to adjoining formations, of both older and younger age, will be discussed in this paper.

DISCUSSION OF PUBLISHED REPORTS.

In his paper on the Cartersville thrust, Hayes[7] described the Ocoee series from the vicinity of Hiwassee and Ocoee Rivers, Tennessee, southwestward in Georgia to a point 50 miles southwest of Cartersville. He concluded that the age of the Ocoee series cannot there be determined because the rocks are thrust northwestward on a great fault of unknown displacement over Paleozoic rocks. Shortly after this paper by Hayes, the U. S. Geological Survey published three folios[8] which cover parts of the Ocoee series and the Chilhowee group. The formations that Hayes and Keith[9] recognized, as published in these folios, are given in the following table.

In the Cleveland folio Hayes correlated the quartzose rocks of Beans and Starr Mountains, Tennessee, with Lower Cambrian rocks of Chilhowee Mountain in the Knoxville quadrangle, and used for those rocks the same formation names that are used by Keith in the Knoxville and Loudon folios. He mapped and described the Ocoee series at the type locality in the gorge of Ocoee River, and showed that the Lower Cambrian rocks of Beans and Starr Mountains are overridden on their southeast side by the overthrust Ocoee series, and that on their northwest side, these Lower Cambrian rocks are overthrust on Paleozoic rocks of the Great Valley. As to the age of the Ocoee series he stated that no fossils have yet been found in these rocks and that they are separated by a great fault from rocks of known age, "but since they bear all the marks of extreme age, it is best to consider them Algonkian until satisfactory evidence to the contrary is found."

[6] La Forge, Laurence, and Phalen, W. T.: 1913, U. S. Geol. Survey, Geological Atlas, Ellijay folio (No. 187), p. 9.

[7] Hayes, C. W.: Idem.

[8] Hayes, C. W.: 1895, U. S. Geol. Survey, Geological Atlas, Cleveland folio (No. 20).

[9] Keith, Arthur: 1895, U. S. Geol. Survey, Geological Atlas, Knoxville folio (No. 16); 1896, Loudon folio (No. 25).

Table of Formation Names of the Chilhowee Group and Ocoee Series—Keith and Hayes.
Thicknesses and descriptions are from the Knoxville folio.

Chilhowee group (Lower Cambrian)	Thickness Feet	
Hesse quartzite	500±	Massive white quartzite
Murray shale	300	Gray sandy shale
Nebo quartzite	500	Massive white quartzite
Nichols shale	500–800	Gray sandy shale
Cochran conglomerate	1,200–1,600	Massive white quartzite with conglomerate at base
Sandsuck shale and Starrs conglomerate lentil	1,000+	Gray argillaceous shale and conglomerate
Ocoee series (Age unknown)		
Clingman conglomerate	1,000+.	Gray quartzite, and conglomerate
Hazel slate	600–800	Black slate with thin quartzite beds
Thunderhead conglomerate	8,000±	Gray quartzite and coarse conglomerate
Cades conglomerate	2,400±	Gray quartzite, fine conglomerate, and slate
Pigeon slate	1,300–1,700	Dark banded slate and interbedded quartzite beds
Citico conglomerate	50–800	Coarse massive conglomerate to fine quartzite
Wilhite slate	0–1,000	Bluish-black slate with lenses of argillaceous limestone and limestone conglomerate
	10,000±	

The Chilhowee group and Ocoee series mapped by Keith in the Knoxville folio (1895) and Loudon folio (1896) cover an area 20 to 50 miles along the strike northeast of the Cleveland quadrangle. When Keith wrote the Knoxville and Loudon folios he believed that the Ocoee series was of Silurian or later Paleozoic age* because in the Knoxville quadrangle he found Ocoee rocks overlying Knox dolomite of Ordovician age, and in the structure sections showed the Ocoee series overlying the Knox dolomite in normal stratigraphic sequence; and in the Mount Guyot quadrangle he[10] found the Ocoee rocks overlying quartzite which, at that time, he considered to be of Silurian

* Subject of general knowledge in Washington at the time. G. W. Stose.

[10] Keith, Arthur: Manuscript map of the Mount Guyot quadrangle: U. S. Geol. Survey files.

age. In the Knoxville and Loudon folios Keith did not express his opinion that the Ocoee series is Paleozoic in age but called it of age unknown. Keith's opinion, however, is expressed by Hayes[11] in the following quotation: "the work of Willis and Keith in east Tennessee, however, has firmly established the position of a corresponding group in the Big Butt range and east of Chilhowee Mountain as belonging to the upper Silurian and the rocks are continuous from one region to the other." In the same paper Hayes writes "Assuming the age of the semi-metamorphic series [Ocoee] to be Silurian . . ." and in a still later place in his paper he refers to the "Silurian Ocoee slates." In 1895, however, Hayes did not believe that the Ocoee series is of Silurian age, for, in the Cleveland folio, he called them of probable Algonkian age. Because Hayes and Keith did not agree on the age of the Ocoee series, it was designated by the U. S. Geological Survey in the Cleveland, Knoxville, and Loudon folios as of age unknown.

After the publication of these three folios, C. R. Van Hise, who was at that time Geologist in Charge of geological investigations in the Southern Appalachians in the U. S. Geological Survey, held a field conference with Hayes, Keith, and J. A. Holmes, at which G. W. Stose was present, to determine, if possible, the relations of the Ocoee series to rocks of known age. The conclusion reached by the conference was that the Ocoee series may have been overthrust on the Knox dolomite and younger Paleozoic rocks in areas where Keith had observed them in apparent normal sequence. To test this assumption, Van Hise assigned G. W. Stose, in 1898, to survey a critical area southwest of English Mountain in the Mount Guyot quadrangle, where Keith had mapped the Ocoee overlapping Ordovician and Silurian strata. Stose's work[12] in that locality showed that the rocks of the Ocoee series are thrust on a low angle fault over Cambrian and Ordovician strata of the Great Valley and that they do not rest on these Paleozoic rocks in normal stratigraphic position as was believed by Keith; and that the fault block was later folded and eroded, producing deep re-entrants in the fault trace and giving rise to outlying remnants of the fault block. This evidence and conclusion were accepted by Van Hise and Keith.

[11] Hayes, C. W.: 1891, Idem., p. 149.

[12] Stose, G. W.: 1898, Manuscript geologic map of part of the Mount Guyot quadrangle, Tennessee, U. S. Geol. Survey files.

Under this interpretation, the areas of Knox dolomite exposed beneath the Ocoee series in Tuckaleeche, Wear, and Cade Coves and other coves in the Knoxville quadrangle become windows in the folded low-angle overthrust which emerges at the west foot of the Great Smoky Mountains. In the Knoxville folio (p. 2), although Keith stated that the Wilhite slate is "particularly altered by cleavage and schistosity around Wear and Tuckaleeche Coves," he considered that this alteration was produced by "squeezing and stretching" and did not recognize that it was the effect of movement on the sole of an overthrust. In papers published in 1902-04, Keith[13] briefly described great folded overthrusts with fensters in the Southern Appalachians, indicating that at that time he acknowledged the overthrust relation of the Ocoee series to the Paleozoic rocks in the Mount Guyot and Knoxville quadrangles. In a later paper Keith[14] named the major fault in this region the Great Smoky overthrust and stated his views as follows:

> "The plane of the overthrust dips gently and is deformed by later folds and faults of great size. Erosion through the thrust plane now exposes Ordovician rocks in windows surrounded by the overthrust Cambrian [Ocoee] rocks. No less than 10 windows form a chain in the Great Smoky Mountains on a northeast-southwest anticline through Cade, Tuckaleeche, and Wear Coves."

The Ocoee rocks pass southwestward from the Knoxville into and across the Nantahala quadrangle. In the Nantahala folio[15] Keith called the rocks of the Ocoee series Cambrian, as he previously had done in the Asheville folio,[16] which was published three years earlier. Keith's usage of names for formations of the Ocoee series and of the Chilhowee group in the Asheville and adjoining quadrangles will be discussed later.

In the Nantahala folio Keith not only assigned rocks of the Ocoee series to the Cambrian but he renamed them, and gave no reasons for the change of age and of formation names. He

[13] Keith, Arthur: 1902, Folded faults in the Southern Appalachians: Science, N. S., Vol. 15; pp. 822-823, abstract; 1904, Internat. Geol. Congress IX, Vienna, Comp. Rend., pp. 541-545.

[14] Keith, Arthur: 1927, Op. cit. abstract, Geol. Soc. Amer., Vol. 38, No. 1, pp. 154-55.

[15] Keith, Arthur: 1907, U. S. Geol. Survey, Geological Atlas, Nantahala folio (No. 143).

[16] Keith, Arthur: 1904, U. S. Geol. Survey, Geological Atlas, Asheville folio (No. 116).

applied the name Great Smoky conglomerate to the Thunderhead and Cades conglomerates; the Hazel slate, which overlies the Thunderhead, he renamed the Nantahala; and the Pigeon slate, which underlies the Cades conglomerate, he renamed the Hiwassee slate. Hiwassee slate at the base of the series is mapped only in the northwest corner of the quadrangle; elsewhere in the quadrangle the Great Smoky conglomerate is mapped at the base and rests on what he called the Carolina gneiss. In this folio he describes other formations above the Nantahala slate which he called Lower Cambrian also. They include the Tusquitee quartzite, Brasstown schist, and Valleytown formation. Where seen by the writers, the Valleytown formation resembles the finer-grained graywacke and arkose of the Great Smoky conglomerate. Bayley[17] also noted the resemblance of these two formations to the south, in Georgia. The Brasstown schist is a black graphitic staurolite schist which resembles the Nantahala slate. The Tusquitee quartzite is a white quartzite which may represent similar quartzite in the Clingman conglomerate. Because these three formations more closely resemble the lithology of the rocks of the Ocoee than they do Lower Cambrian formations, the writers tentatively regard them as part of the Ocoee series.

In the Nantahala folio Keith mapped also as Cambrian three other formations, which he placed above the Valleytown formation in the following order, from the base upward: Murphy marble, Andrews schist, and Nottely quartzite. The writers agree with Keith that these three formations may be Cambrian, but they are not convinced that they are part of the sequence which includes the Valleytown and associated formations. The writers suggest that these three formations may be exposed in windows in the Great Smoky overthrust block that contains the Valleytown formation and other members of the Ocoee series. They suggest also that the Nottely quartzite is the lowest, and the Murphy marble is the highest of these three formations. The calcareous and ferruginous Andrews schist may be transitional beds between the Nottely quartzite, which might represent the Erwin quartzite, and the Murphy marble, which might represent the Shady dolomite.

In the Ellijay quadrangle, which lies southwest of the Nan-

[17] Bayley, W. S.: 1928, The Geology of the Tate quadrangle, Georgia: Georgia Geol. Survey, Bull. 48, p. 68.

tahala, La Forge and Phalen[18] extended Keith's mapping of formations into Georgia and called all the formations Cambrian for the reason that "they are an alternating series of shales and sandstones which do not differ from Lower Cambrian shales and sandstones." In the report on the Tate quadrangle, which lies south of the Ellijay, Bayley[19] also followed the same usage of formation names and age determinations. It is significant, however, that both La Forge and Bayley stated that these so-called Cambrian rocks are part of Safford's Ocoee series.

The Murphy marble and Nottely quartzite extends in a narrow band southwestward from the Nantahala quadrangle across the Murphy, Ellijay, and Tate quadrangles. In the Ellijay quadrangle La Forge places faults on both sides of the belt composed of these two formations, and in his Fig. 5, page 9, shows the extension of these faults northeastward into the Murphy and Nantahala quadrangles and southwestward into the Tate quadrangle. The fault on the northwest side he called the Murphy fault, and the one on the southeast side, the Whitestone fault. He shows a photograph (his Fig. 6) of the Whitestone fault at Whitestone, Georgia, where the overthrust Nantahala slate rests on the Murphy marble. In the report on the Tate quadrangle Bayley states (p. 122) that the Whitestone fault of La Forge "is believed to pass into the Tate quadrangle and become the dominating cause of the distribution of most of the marble [Murphy] in the area." As evidence of faulting he says (p. 73) "In some places the fault crosses the strike of the marble diagonally, thinning the width of its exposures or cutting out the belt completely," and "folding east of the fault line brings the marble to the surface at several places where it is entirely surrounded by siliceous schist." Neither La Forge nor Bayley stated that the Murphy marble and Nottely quartzite are exposed in windows in a fault block, but their descriptions of the fault contacts and the structural relations of the marble and quartzite to the other rocks support the writers' suggestion that the Murphy marble and Nottely quartzite may be exposed in a window in the overthrust Ocoee series. To establish the correct stratigraphy, age, and structural relations of the Murphy marble, Andrews schist,

[18] La Forge, Laurence, and Phalen, W. T.: Idem.
[19] Bayley, W. S.: 1928, Idem.

and Nottely quartzite, more detailed field study of the area is needed.

In the Dalton and Cartersville quadrangles, Georgia, which lie west of the Ellijay and Tate quadrangles, Hayes, in his paper on the Cartersville thrust, mapped all the rocks in the belt east of that thrust as Ocoee. In a paper on the Talladega series and on the geologic map of Georgia, Crickmay[20] separated these rocks into two groups. Those in the southeastern part of the belt he called the Talladega series, of probable pre-Cambrian age; those in the northwestern part of the belt he called the Ocoee series, of Cambrian age. He placed the line of separation along a fault which branches from the Cartersville fault of Hayes and extends northeastward. The relation of the Talladega series to the Ocoee series will be discussed later in this paper.

On the preliminary map of the Mount Guyot quadrangle Keith applied the name Snowbird formation to the rocks which represent the Citico conglomerate and Wilhite slate of the Ocoee series in the adjoining Knoxville quadrangle. The Snowbird formation is stratigraphically continuous from its type locality on Snowbird Mountain, in the Mount Guyot quadrangle, northeastward into the Asheville, Greeneville, and Roan Mountain quadrangles. In the folios covering the last named three quadrangles Keith[21] called the Snowbird formation and the overlying Hiwassee slate Lower Cambrian, although he had formerly placed equivalent rocks in the Ocoee series of unknown age. Furthermore, in the Roan Mountain folio Keith correlated the Snowbird formation and Hiwassee slate with the Unicoi formation of known Lower Cambrian age. In the three folios just mentioned, he applied, to the formations that overlie the Hiwassee slate, formation names of the well-established Lower Cambrian Chilhowee group. (See table, p. 381).

In the Asheville and Greeneville folios Keith states that the Snowbird formation overlies granites of Archean age—the Max Patch and Cranberry granites of Keith. In the Mount Guyot

[20] Crickmay, G. W.: Status of the Talladega series in Southern Appalachian stratigraphy: Geol. Soc. Amer. Bull., Vol. 47, pp. 1371-1392; 1936, Geological Map of Georgia; 1939, Georgia Div. of Mines, Mining and Geology, p. 84.

[21] Keith, Arthur: 1904, Asheville folio, Op. cit.; U. S. Geol. Survey; 1905, Geological Atlas, Greeneville folio (No. 118); 1907, Roan Mountain folio (No. 151).

quadrangle he mapped the Snowbird formation in a similar position. The fact that the Unicoi formation of Lower Cambrian age overlies granites of Archean age at many places in the area northeast of the Asheville quadrangle may have been Keith's reason for assigning to the Lower Cambrian the Snowbird formation which has similar stratigraphic relations to those granites. The stratigraphic relation which the Snowbird formation bears to the underlying granites proves that the Snowbird is younger than the granites of Archean age but does not prove that it is Lower Cambrian. The Snowbird and overlying rocks, called Cambrian by Keith, are stratigraphically continuous southwestward into the Ocoee series of the type locality. In a later part of this paper the writers present evidence to show that the Snowbird and overlying formations lithologically resemble the Ocoee series and not Lower Cambrian rocks and that they are not of Lower Cambrian age.

The usage of the same formation names for the rocks of two separate series, which have not been proved to be equivalent and which the writers believe to be of different ages, has led to the stratigraphic confusion which this paper attempts to clear up.

The following chart tabulates the formation names used by Keith and La Forge for rocks which are part of the Ocoee series as used by Hayes and Safford and as defined in this paper. It shows the implied correlation of rocks that Keith, in the Knoxville and Loudon folios, called Ocoee, of age unknown, with rocks in adjoining areas where he called them Lower Cambrian. The names taken from Cambrian formations of the Chilhowee group are placed in quotation marks because the writers question the use of Cambrian formation names for formations of the Ocoee series. Diagonal lines indicate an hiatus of formations.

GENERAL STRUCTURE.

In order to make clear the stratigraphic problems discussed in this paper, the general structure of the region will be described briefly. (Fig. 2.) This description is largely summarized from a report now in preparation by the writers on the "Structure of the Southern Appalachian Mountains."

In southern Virginia and northern Tennessee, the western border of the Appalachian Mountains is marked by the Holston Mountain overthrust, which has ridden northwestward over

Chart of Formation Names Applied to Formations of the Ocoee Series in Respective Folios.

Ellijay La Forge 1913	Nantahala Keith 1907	Knoxville Keith 1896	Mount Guyot Keith (Unpublished)	Asheville Keith 1905	Greeneville Keith 1905	Roan Mountain Keith 1907
		Clingman conglomerate		"Nebo quartzite"	"Murray slate" "Nebo quartzite"	"Murray slate" "Nebo quartzite" } "Erwin quartzite"
Nantahala slate	Nantahala slate	Hazel slate		Nantahala slate "Nichols slate"	"Nichols slate"	"Nichols slate" } "Hampton shale"
Great Smoky conglomerate	Great Smoky conglomerate	Thunderhead conglomerate Cades conglomerate	Great Smoky conglomerate	Great Smoky conglomerate ("Cochran conglomerate")	"Cochran conglomerate"	"Cochran conglomerate" } "Unicoi formation"
	Hiwassee slate	Pigeon slate	Hiwassee slate	Hiwassee slate (Southern part)	Hiwassee slate	Hiwassee slate } "Unicoi formation"
		Citico conglomerate Wilhite slate	Snowbird formation	Snowbird formation	Snowbird formation	Snowbird formation } "Unicoi formation"
Carolina gneiss	Carolina gneiss		Carolina gneiss, granite complex	Carolina gneiss, granite complex	Granite complex	Granite complex

rocks of the Great Valley.[22] The writers have described the Holston Mountain overthrust as follows: The Holston Mountain overthrust "is a major overthrust fault which extends southwest along the front of Poplar Camp, Iron, and Holston Mountains across Virginia to the Tennessee State line, south of Damascus, Virginia, and southwestward into Tennessee." Lower Cambrian quartzites that form Iron Mountain in Virginia extend southwestward into Tennessee, where they occur in two parallel mountain ranges on the two sides of a synclinal valley. In Tennessee the ridge on the northwest side of the syncline is called Holston Mountain, and the ridge on the southeast side, Iron Mountain. In the Roan Mountain quadrangle, Holston Mountain ends three miles north of Elizabethton, Tennessee, and Iron Mountain extends as a continuous ridge to a point five miles southeast of Erwin, Tennessee. In southern Virginia and northern Tennessee, the Lower Cambrian quartzites that form Iron and Holston Mountains lie on the western border of the Holston Mountain overthrust block as far south as the end of Holston Mountain. There the Erwin quartzite is cut off by the Holston Mountain fault. It is the writers' interpretation that the Holston Mountain thrust passes southwestward into the dolomites and limestones which overlie the Erwin quartzite of the thrust block, and lies within these dolomites and limestones from the south end of Holston Mountain to the north end of Buffalo Mountain. At a point just southwest of Cherokee Mountain and southwestward, the Great Smoky overthrust block has ridden northwestward over the Cherokee Mountain block, concealing it in places and leaving narrow remnants of Lower Cambrian rocks in the Cherokee Mountain block on the northwest side of the Great Smoky overthrust block.

In their paper[23] previously referred to, the writers mention a window in the Holston Mountain overthrust block, southeast of Holston and Iron Mountains, which they named the Taylors Valley window. At this window, the overthrust rocks have been

[22] Stose, G. W., Jonas, A. I., and others: 1938, XVI International Geological Congress Guidebook 3, Excursion A3, Southern Appalachian region, pp. 7, 86, pl. 26, 1933; A southern limestone facies of the Lower Cambrian dolomite in Wythe and Carroll Counties, Virginia: Virginia Geologcal Survey, Bulletin 51-A, p. 23.

[23] Stose, G. W., and Jonas, A. I.: 1938, Idem., Virginia Geological Survey, Bull. 51-A, p. 23.

bowed up and, Lower Cambrian and pre-Cambrian rocks which lie beneath the Holston Mountain overthrust block have been exposed by erosion. The Holston Mountain overthrust block and the Taylors Valley window in southern Virginia and northern Tennessee are diagrammatically shown in Fig. 2 of another paper by the writers.[24] The Taylors Valley window extends from its northeast end, north of Taylors Valley in southern Virginia, 60 miles southwestward in Tennessee and North Carolina, and ends eight miles south of Erwin, in the southwestern part of the Roan Mountain quadrangle. (See Fig 2.) The Holston Mountain overthrust block rests in overthrust position on the Pulaski overthrust block of the Great Valley, hence the rocks exposed in the Taylors Valley window are part of the Pulaski block. Lower Cambrian quartzites of Stone Mountain form the eastern border of the window in southern Virginia and northern Tennessee, and, with short interruptions, these quartzites form the eastern border of the window to Unicoi, Tennessee. Cambrian quartzites, which underlie the Shady dolomite and Rome formation, are exposed also in anticlines in the center of the window northeast of Hampton, Tennessee.

In the region southeast of the area described in this paper, the writers have mapped another large window in the overthrust block. This window, called Grandfather Mountain window because it includes Grandfather Mountain, is about 15 miles wide and 25 miles long. Along the borders of the window the pre-Cambrian rocks of the overthrust block are mylonitized on the sole of the overthrust and the mylonites dip gently away in every direction from the window, indicating that the overthrust block was domed into a broad anticline. The sequence and lithology of the rock units exposed in the window is the same as that in the Holston Mountain block. The injection complex is overlain by the Unicoi formation, which forms Grandfather Mountain and contains the characteristic basalt flows. The Unicoi formation is overlain by the Hampton shale, the Erwin quartzite, and the Shady dolomite, which forms the western border of the window. The Grandfather Mountain window is included in Keith's Cranberry and Mount Mitchell folios and also in the Morganton quadrangle. Keith did not

[24] Jonas, A. I., and Stose, G. W.: 1939, Age relation of the pre-Cambrian rocks in the Catoctin Mountain-Blue Ridge and Mount Rogers anticlinoria in Virginia: Amer. Jour. Sci., Vol. 237, Fig. 2.

recognize the structure as a window in either of his folios. In the structure sections of the Cranberry folio he showed a fault on the north and west sides of the area defined in this paper as a window, on which the pre-Cambrian rocks were thrust southeastward, and in his text he described a later fault on the southeast side where the movement was to the northwest.

The Great Smoky overthrust (see Fig. 2) extends from southeast of Cherokee Mountain southwestward along the front of the Appalachian Mountains of Tennessee and passes into the Cartersville overthrust in Georgia. The Great Smoky block has been thrust northwestward over the Cherokee Mountain block, and in places on the northwest side overrides it completely and rests on the rocks of the Great Valley. At the northeast end of the Great Smoky block, southeast of Cherokee Mountain, the Great Smoky overthrust curves sharply around the north end of Buffalo Mountain, then turns southwestward along the southeast side of the block, passing one-half mile north of Erwin, and extends southwestward to the vicinity of Sylva, North Carolina, where the Tusquitee overthrust rides over the Great Smoky block. At the northeast end, north of Erwin, Tennessee, the Great Smoky block is four miles wide; north of Sylva it is 32 miles wide. At the northeast end, in the Roan Mountain quadrangle, the Great Smoky block rests on the Lower Cambrian rocks of Cherokee Mountain on the northwest, and on younger Paleozoic rocks of the Holston Mountain block on the southeast. Southwest of the Roan Mountain quadrangle, the Great Smoky block on its southeastern side rests largely on the early pre-Cambrian injection complex of the Holston Mountain block. The major part of the Great Smoky block is made up of the Ocoee series, but Buffalo Mountain, at the northeastern end of the block, is formed of Lower Cambrian quartzite. The early pre-Cambrian injection complex, on which the Ocoee series rests, occurs in places on the southeast border of the block.

The Great Smoky overthrust block moved northwestward and the fault plane on the northwest side of the thrust block dips southeast. On the southeast side of the thrust block southwest of Erwin a gentle northwest dip of the thrust plane is indicated by the persistent northwest dip of the schistosity in the rocks of the Ocoee series and of the granitic rocks of the injection complex, near the sole of the thrust. The northeast end of the Great Smoky block is, therefore, a narrow slice

which is folded into a syncline. It has been shown that the Holston Mountain block also is folded and that the Taylors Valley window is exposed in a broad anticline in that thrust block. Two miles southeast of Erwin, the Holston Mountain thrust fault dips northwestward away from the rocks of the Taylors Valley window. One mile northwest of Erwin the Great Smoky overthrust fault dips northwestward away from the rocks of the Holston Mountain block. It is clear that the narrow strip of the Holston Mountain block, lying between the northwest border of the Taylors Valley window and the southeast border of the Great Smoky block, is part of the southeast limb of the syncline which encloses the synclinal slice of the Great Smoky block, and that both blocks were folded together after the Great Smoky block was overthrust.

Folding of the Great Smoky thrust slice northwest of Erwin is indicated also by the deep embayment in the fault trace in that vicinity and by a small window in the thrust block which exposes underlying dolomite of the Holston Mountain block in the valley of Nolichucky River a half mile west of the embayment. Folding of the block farther southwest is shown not only by the sinuous character of the northwest trace of the fault but by the presence of windows where anticlines in the Great Smoky thrust plate have been cut through by erosion. The windows in the Knoxville quadrangle have been previously mentioned. A large window in the Great Smoky overthrust block occurs in the Asheville quadrangle at Hot Springs, North Carolina, where the Lower Cambrian quartzites and overlying limestones of the overridden block are exposed. This structure, mapped by the writers as a window on the Geological map of the United States published in 1933, has not been previously described. In the Asheville folio Keith[25] described the Hot Springs fault as a fault of unusual character but did not recognize that it bounded a window in a great overthrust. He stated "The great fault which passes just north of Hot Springs is one of the most unusual in the Appalachians. Its outcrop forms a nearly complete oval and its planes, if extended upward, would almost unite in a dome. . . . its plane dips successively toward all points of the compass. . . . .The area enclosed by the fault plane thus represents a down-thrown mass upon which the adjoining rocks were piled high from all sides." In the

[25] Keith, Arthur: 1908, Op. cit., Asheville folio, p. 8.

structure sections of the folio he shows a dome structure with the rocks on opposite sides thrust toward the center. Keith's interpretation appears to be an impossible structure. His recorded facts are in keeping with the writers' interpretation of a dome-shaped folded overthrust plate which has been eroded, exposing underlying rocks in an oval-shaped window.

LOWER CAMBRIAN QUARTZOSE ROCKS.

The writers have studied in detail the Lower Cambrian quartzose rocks at many places from Pennsylvania to southwestern Virginia. They have published sections and descriptions of these Lower Cambrian rocks in reports of State Surveys and of the U. S. Geological Survey. During their recent field work in the Appalachian Mountains of southern Virginia and the adjoining region in Tennessee and North Carolina the writers have studied the Lower Cambrian quartzites of that region and have compared their observations with Keith's usage of formation names, his mapping of formation units, and his structural interpretations as shown in the Cranberry and Roan Mountain quadrangles. The writers have recently completed and submitted for publication to the Virginia Geological Survey a report entitled "The Geology and Mineral Resources of the Gossan Lead and Adjacent Area in Virginia," which contains descriptive sections of these quartzites.

In southern Virginia the Unicoi formation, which forms the base of the Lower Cambrian quartzose rocks, overlies the Mount Rogers volcanic series[26] of late pre-Cambrian age and the injection complex of early pre-Cambrian age, and is stratigraphically discordant with both of these series. The section of the Lower Cambrian quartzose rocks exposed in southern Virginia is as follows: (see table on page 387).

Throughout the Holston Mountain overthrust block in southern Virginia and northern Tennessee, the stratigraphy, sequence, and lithology of the Lower Cambrian formations are the same, the full section of quartzose rocks is present in many places, and the formation names given in the following table of the rocks in Iron Mountain, Virginia, can be applied. The Unicoi formation throughout that area contains the characteristic basalt flows. At the northeast end of the synclinal slice of the Great Smoky overthrust block, also, the Lower

[26] Jonas, A. I., and Stose, G. W.: Idem.

Lower Cambrian Quartzose Formations in Iron Mountain, Virginia.

Name	Description	Thickness, feet	
Erwin quartzite	Thin-bedded ferruginous dark quartzite and thick-bedded ridge-making vitreous white quartzite	200 – 300	450 ±
	Dark argillaceous and buff banded quartzite	200 ±	
Hampton shale	Gray to black argillaceous shale with few thin rusty quartzite beds		1,500 ±
Unicoi formation	White and dark-banded gray and green hard quartzite with some arkosic quartzite	600 ±	1,700 ±
	Amygdaloidal basalt flows with interbedded argillite, conglomerate, and quartzite	400 ±	
	Arkosic quartzites, some containing coarse grains of fresh pink feldspar and pebbles and grains of white quartz, and interbedded argillite	700 ±	

Cambrian quartzites that form a large part of Buffalo Mountain have the characteristic lithology of the Unicoi formation.

CHILHOWEE GROUP.

In this paper the term Chilhowee group and the names of formations in that group will be restricted to Lower Cambrian quartzose rocks of the overthrust block which begin in Cherokee Mountain and extend southwestward to Beans Mountain, Tennessee. These Lower Cambrian formations lie in a detached thrust block and are not stratigraphically continuous with any other Lower Cambrian rocks. The formations in this group have been given names taken from Chilhowee Mountain in the Knoxville quadrangle. The distribution of the Chilhowee group, as interpreted by the writers, agrees very closely with that of Safford shown on his map of 1869. (See Fig. 1.) The longest belt of the Chilhowee group extends from Cherokee Mountain southwestward for a distance of 60 miles. The Chilhowee group also forms English Mountain, southwest of Newport, Tennessee, Chilhowee Mountain, south of Knoxville, Tennessee, and Starr and Beans Mountains, east of Cleveland, Tennessee.

AGE AND CORRELATION OF CHILHOWEE GROUP.

The type locality of the Chilhowee group is in Chilhowee Mountain in the Knoxville quadrangle. Lower Cambrian fossils have been found by Walcott[27] in these rocks at two places; in the gap of Little River in Chilhowee Mountain, and south of the crest of the mountain at a point south of Montvale Springs. The fossils were found in calcareous sandy shales which Keith mapped as Murray shale. (See Fig. 2.) Fossils occur in Lower Cambrian quartzites at many places along their outcrop from Pennsylvania to Tennessee, but all fossils heretofore collected came from the uppermost calcareous shales that mark the transition from Erwin (Antietam) quartzite into the overlying Shady (Tomstown) dolomite. Therefore the writers doubt that the shale in which Walcott collected Lower Cambrian fossils is Murray shale. Keith mapped Knox dolomite directly southeast of the beds in which the fossils were found in the gap of Little River, and his map and structure section show that the Knox dolomite in this area overlaps onto Murray shale and Nebo quartzite, although in his text Keith did not mention this marked stratigraphic break. Because no unconformity at that horizon is known in the neighboring region, it seems more probable that the poorly exposed dolomite which was mapped as Knox dolomite is Shady dolomite, and that it overlies in normal sequence the shaly beds in which fossils occur. The Hesse and Nebo quartzites are so similar that they could easily be confused in the field, hence the writers believe that the quartzite mapped by Keith as Nebo in the Little River gap may be Hesse quartzite; and that the calcareous shales in which the fossils were found may be transitional beds at the top of the Hesse and are not Murray shale. If this suggested interpretation proves to be correct, the quartzite exposed in the gap of Little River is Hesse quartzite containing fossiliferous, shaly beds at the top which dip southeast and pass normally beneath Shady dolomite. The writers made this interpretation of the sequence when they briefly examined the rocks in the gap of Little River, but more detailed fieldwork is necessary to establish the sequence there. There is, however, no question that the rocks of the Chilhowee series are of Lower Cambrian age.

In the Cleveland folio, Hayes shows the Lower Cambrian

[27] Keith, Arthur: 1895. Op. cit. Knoxville folio, p. 8.

quartzites in Starr and Beans Mountains in a syncline with the Nebo quartzite and Murray shale in the center of the fold. The oldest formation mapped by Hayes and Keith in the Chilhowee group is the Sandsuck shale. Hayes mapped a conglomerate within the Sandsuck shale, which he named the Starrs conglomerate. With the present knowledge, it is not possible to decide which formation, if any, in the Chilhowee type section represents the Unicoi formation, but it is evident that the lower part of that formation which contains the basalt flows is not present because neither Hayes nor Keith describe such flows in the section. Although the sequence of the Lower Cambrian formations in the Cleveland and Knoxville quadrangles is well established, the exact equivalence of formations of the Chilhowee group with formations of the Cambrian section (see p. 387) in the Holston Mountain block in northeastern Tennessee and southwestern Virginia cannot at present be definitely proved.

The following table shows the Cambrian formation names used in the Cleveland, Knoxville, and Loudon folios and Keith's correlation of these formations with Cambrian formation names used in the northeastern part of the Roan Mountain quadrangle.

Correlation of Cambrian Formations by A. Keith.

	Cleveland, Knoxville, and Loudon quadrangles	Roan Mountain quadrangle	
		Southwestern part	Northeastern part
Chilhowee group	Hesse quartzite	Hesse quartzite	
	Murray slate	Murray slate	Erwin quartzite
	Nebo quartzite	Nebo quartzite	
	Nichols slate	Nichols slate	Hampton shale
	Cochran conglomerate	Cochran conglomerate	
	Sandsuck shale	"Hiwassee slate"	Unicoi formation
	(Lower rocks not exposed in Knoxville, Loudon, or Cleveland quadrangles)	"Snowbird formation"	

In northern Tennessee and North Carolina as far south as the central part of the Roan Mountain quadrangle, Keith used for Cambrian formations names of the northern sequence, and in the southwestern part of the quadrangle he used names of the Chilhowee sequence. In places he used a mixture of the names of the two sequences in an effort to merge them along the strike. Because the base of the Cambrian is not exposed in Chilhowee, Starr, or Beans Mountains and there is no formation in the Chilhowee group of the type section equivalent

to the entire Unicoi formation, Keith, in his later reports, used the names Hiwassee slate and Snowbird formation for Cambrian rocks below the Cochran conglomerate. These two names are names of Ocoee formations, and should not be used for Cambrian formations. In Buffalo Mountain and adjacent areas, Keith mapped the three divisions characteristic of the Unicoi formation but called the formation Snowbird.

In the legend of the geologic map of the Roan Mountain folio Keith places the Erwin quartzite as equivalent to the Hesse quartzite only, but in the text of the folio he states that the quartzite he mapped as Erwin in the northeastern part of the quadrangle is the equivalent of both the Hesse and Nebo quartzites, and that the Hampton and Nichols shales are approximately equivalent. In Cherokee Mountain he mapped the main ridgemaker above the Nichols shale as the Nebo quartzite, and the beds above the Nebo and below the Shady dolomite he mapped as Murray shale and Hesse quartzite. On the basis of field observations at the northeast end of Cherokee Mountain, the writers regard the Nebo quartzite, Murray shale, and Hesse quartzite as equivalent to the Erwin quartzite, and believe that Keith's correlation of the Erwin as expressed in the legend of the folio is inaccurate.

To be continued.

THE HUDSON VALLEY BELT OF GRAPTOLITE SHALES AND NEGATIVE ANOMALIES OF GRAVITY.

RUDOLF RUEDEMANN.

ABSTRACT. In reference to Longwell's paper on the Geologic Interpretation of Gravity Anomalies in the Southern New England-Hudson Valley region the writer points to the great thickness of the graptolite shales reached and the great depth of the geosyncline indicated by the radiolarian fauna and suggests that the Levis trough with the graptolite beds may have been the central portion of a mediterranean sea, the shallow littoral portion of which was formed by the adjoining so-called Chazy and eastern troughs. The great thicknesses of the westerly adjoining Schenectady and Canajoharie beds are considered as partly explained by the northwest swing of the negative isanomalies in the Mohawk valley and partly as a secondary effect of the strong sedimentation in the adjoining geosyncline.

PROFESSOR CHESTER R. LONGWELL published last year a paper on the Geologic Interpretation of Gravity Anomalies in the Southern New England-Hudson Valley region which proves of great interest to the students of graptolite shales by explaining the presence of these shales and their enormous thickness in the Hudson Valley region.

The presence and the great thickness of the graptolite shales of Ordovician age in the belt extending from the St. Lawrence River through the Lake Champlain basin and the Hudson Valley region has ever been a puzzle to the writer since he began the study of these shales and their graptolite biota.

It was obvious that there had existed throughout Ordovician time, beginning in late Cambrian time (if we include the Schaghticoke shale) and continuing to the end of Ordovician time, a great depression in this belt. The graptolites (see Ruedemann 1942) proved that the open ocean had access to this basin most of the time and that oceanic currents were able to sweep through it from the north bringing with them the graptolite faunas as free plankton and as epiplankton attached to seaweeds. It has even been claimed by the writer (1935, 1943) that the radiolarian fauna found in the chert associated with the graptolites indicated abyssal depths of over 12,000 feet attained at times by this intensely mobile belt, a portion of the St. Lawrence geosyncline.

It appears now from Longwell's excellent paper that a belt of strongly negative gravity anomalies discovered by pendulum observations of the United States Coast and Geodetic Survey extends through the Hudson River Valley from the north and is flanked on both sides, in Massachusetts and Connecticut on the east, and the Catskill Mountains in the west by strongly positive anomalies. In the deepest depression, east of Albany the anomaly amounts to −42 milligals and continues south, crossing the Hudson River north of the Highlands at −40 milligals, while in western Massachusetts and central Connecticut it rises to +40 milligals and on the other side under the eastern Catskills to +28 milligals.

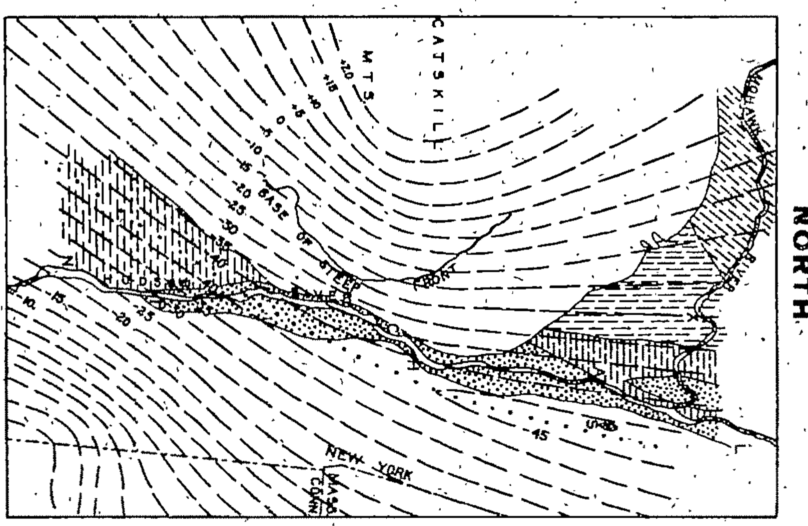

Fig. 1. Chart of the negative anomalies of the Hudson River Valley and the graptolitiferous formations connected with it.

Dotted=Normanskill beds: horizontal lines Snake Hill beds; vertical lines Schenectady beds; oblique lines Canajoharie shale. L=Logans Line separating the overthrust Lower Cambrian Nassau beds in the east from the graptolite beds. The latter are in the west covered by the Silurian and Devonian Helderberg formations. S=Snyders Lake inlier. A=Albany, H=Hudson, P=Poughkeepsie, N=Newburgh, X=Schenectady.

The anomalies are dependent according to Longwell's suggestion on the different distances of the base of the sial shell from the surface of the Earth, disregarding the influence of rock masses of abnormal densities at the surface, as such (volcanics) are not present in the region. Negative anomalies result from downward bulges of the sial shell.

To quote from Longwell (p. 589): "The two principal groups of negative anomalies are in the Hudson Valley belt and the Rhode Island basin, both of which were areas of subsidence, sedimentation and severe orogeny in the Paleozoic era."

We are here interested only in the Hudson Valley belt, the site of the graptolite shales, and wish to present some figures illustrating the amount of subsidence and sedimentation that took place there.

In the St. Lawrence geosyncline, where the graptolite beds were deposited, we obtain the following figures (Ruedemann, Bull. 285):

Name of formation	Minimum thickness	Maximum thickness in feet
Nassau beds	153	785
Troy beds	25	100
Schodack shales and limestone	20	200
Diamond quartzite	10	40
Bomoseen grit	18	50
Schaghticoke shale	30	30+
Deepkill shale	300	300+
Bald Mountain limestone	70	70+
Normanskill shale (Dale)	1200	2500
Rysedorph conglomerate	2.5	10
Tackawasick limestone	50	50+
Snake Hill shale	3000	3000+
	4885.5	7355+

The Lower Cambrian and Ordovician deposits of the geosyncline amount roughly to a minimum of 5000 ft. and a maximum of 7400 ft., or one mile and one and one-half miles respectively.

The pure graptolite shales are:

Schaghticoke shale	30 feet+
Deepkill shale	300 feet+
Normanskill shale	2500 feet+
	2830 feet or approximately one-half mile.

The impure graptolite shale (Snake Hill shale) amounts to 3000 ft. or another half mile.

The graptolite shales are black, very fine-grained sediments which were deposited at the lower slopes of continental shelves or at the bottom of the abysses, some at 12,000+ feet. They show by the rapidly changing graptolite faunas in often small

thicknesses of beds, that they were very slowly deposited during long lapses of time. It is therefore certain that they represent a very great interval of time and a long continuation of the deep depression of the geosyncline, from late Cambrian time through the Ordovician era. This in itself is proof of a long existing fundamental condition such as the downward bulge of the sial foundation affords.

It may be added here that the discovery of radiolarian chert (Ruedemann & Wilson, 1935) in the graptolite shale has afforded another significant fact, namely that the bottom of the geosyncline may at times have dropped to depths of more than 12,000 feet, according to the evidence furnished by the radiolarian genera. This strange phenomenon can also be best explained by the influence of the great downward bulge of the sial fundament, as indicated by the strongly negative anomalies.

A peculiar problem is presented by the region to the west of the geosyncline, in which the great thicknesses of the Schenectady beds and of the Canajoharie shale, homotaxial to the Snake Hill shale, were deposited, in Trenton time. The Schenectady beds, reaching (Ruedemann, Bull. 285, p. 34) a thickness of 1000 feet and possibly 2880 feet consist of prevailing sandstone with interbedded shales. They contain a flora, consisting of a seaweed (*Sphenophycus latifolius* Hall), the index fossil, and a fauna of graptolites, brachiopods, gastropods, conularids, cephalopods, trilobites, ostracods and numerous forms of eurypterids, none of them in abundance.

The Canajoharie shale, which is partly contemporaneous with the Schenectady beds and contains an impure graptolite fauna of a few species mixed with other fossils extends westward from the Schenectady belt into the Mohawk valley, where it attains a thickness of over 1500 feet. Former investigations by the writer (Ruedemann, 1897), based on the parallel directions of the graptolites and cephalopods indicated a strong current sweeping from the northeast across the lower southern Adirondack massif and around it toward the west, where the shale is replaced by the Trenton limestone, deposited in purer water and of much less thickness.

The great thicknesses of the Schenectady and Canajoharie beds and the continued depression of the area of their deposition are, at least in part, explainable by the fact that the lines of negative anomalies swing sharply to the northwest under the eastern Catskills and in the lower Mohawk valley, indicating

a widening of the downward bulge of the sial in that direction. It is further possible that the strong sedimentation in the geosyncline had a secondary effect on the beds of the neighboring region. The St. Lawrence geosyncline has been subdivided by Ulrich and Schuchert (1902) into several troughs, which were independent of each other at times. The central trough which contains the Lower Cambrian and the graptolite beds they term the Levis trough. This was flanked on the west by the Chazy trough which holds the Potsdam-Beekmantown-Chazy-Trenton series, and a third trough on the east. The writer has more recently (1942) held the view that the St. Lawrence geosyncline on account of the great depth it reached at times and the passage of the successive graptolite faunas through it may have reached the dimensions of a mediterranean sea. At that time the Levis trough would have formed the abyssal depths while the shallower portions on both sides—the Chazy and eastern troughs with the Chazy and eastern sequences—received the littoral deposits. However, that may be, it is obvious that only the Levis trough occupied the depression of the negative anomalies while the flanking troughs or the coastal regions of the mediterranean sea were in the areas of positive anomalies.

The great mass of Schenectady beds is capped in the Indian Ladder region near Albany by 410 feet of the Indian Ladder beds, consisting of black shales with interbedded calcareous sandstone layers. These beds are of younger age than the Utica and are homotaxial to the Frankfort shale of New York and the Southgate member of the Eden shale of Cincinnati. They occupy a narrow trough, only about five miles wide, extending from south to north. As indicated by the fauna the trough extended far into Pennsylvania where it connected with the west.

This strange formation marks a final narrowing of the downward depression in the area where the Schenectady beds were deposited.

A recent paper by F. J. Pettijohn (1943) deserves special notice in this place. The author points to the special type of sedimentation, which he calls the orogenic type, that has taken place in the Archean geosynclines of Canada. These were filled rapidly "with incompletely weathered and relatively unsorted material. The result was the production of conglomerates and graywackes."

It may be concluded that the Upper Normanskill beds, the Austin Glen member, consisting largely of grit and some conglomerate indicate such a condition of more rapid filling of the geosyncline than the lower black Normanskill shales do.

As is well known James Hall and Dana had recognized that the Appalachian geosyncline was the site of more rapid sedimentation of clastic material than the region to the west where the Trenton limestone was deposited. We know now that only a portion of the deposits in the geosyncline are of Trenton age and the others, especially the older ones, are not present west of the geosyncline.

From the deposition of the Normanskill grit it may be inferred that the geosyncline, which once reached abyssal depths was later being filled by the clastic materials, furnished by the beginning orogenic activity of the adjoining regions, notably the eastern.

No study has been made so far of the possible presence of megavarves, indicating cycles of seasonal changes.

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ALBANY, NEW YORK.

SCIENTIFIC INTELLIGENCE

Chemistry.

Quantum Chemistry; by Henry Eyring, John Walter and George E. Kimball. Pp. vi, 394; many figs. New York, 1944 (John Wiley and Sons, $5.00).—The contents of the book may be divided roughly into three parts. By the end of the first 120 pages, the reader will find that he has covered most of the mathematical essentials of the subject. These include discussions of classical and quantum mechanics; the differential equations which are needed and their applications to a few simple systems, including the hydrogen atom and finally, the various approximation methods. The next part of the book applies this material to problems of atomic and molecular structure and to the study of valence. In these sections, the authors have introduced one further mathematical technique, that of group theory and they find it helpful throughout the rest of the book. It is very clearly and simply presented and should serve to convince the student that this subject is not only useful but understandable. The final section of the book deals with further applications such as quantum statistical mechanics, reaction rates, electric and magnetic phenomena and a few special topics. Some mathematical details, including a table of group characters will be found in a series of nine appendixes.

The authors "have attempted to put into a systematic, condensed form the tools which have been found useful in efforts to understand and develop the concepts of chemistry and physics. . . . The book has been written at the level of the graduate student in chemistry." It should not take long for the reader to convince himself that these aims have been fulfilled in a highly satisfactory manner. It seems likely that this book will become the standard text for the elementary graduate course in quantum theory in most schools. It is highly recommended, not only for that purpose but also for self-study. GEORGE M. MURPHY.

Paleontology and Mineralogy.

Paleontology of the Marine Tertiary Formations of Oregon and Washington; by Charles E. Weaver. Univ. of Washington Publications in Geology, Vol. 5, Pp. XI+789, 104 pls. (Univ. of Washington Press, Seattle), 1943.—It is just over 100 years since Conrad described the first marine fossils from Oregon. Since then Tertiary fossils have been collected from over 700 localities in Oregon and Washington, yielding a total of 879 species. Descriptions of these fossils are scattered through a vast literature and many of the early ones are brief, deficient, and poorly illustrated. Most of the generic assignments are now out of date and many of

the species are involved in confusion. The types are scattered through numerous museums and some of them are now lost.

Having worked on these faunas for some 35 years, Doctor Weaver realized the necessity of a comprehensive restudy that would bring the taxonomy and the descriptions up to date, and this he has done in this three volume *magnum opus.*

He has restudied every type that could be located and, in a tabular list of all the species, indicates their present location and catalogue numbers. For most species he has quoted the original description and supplemented it by his own observations. In 104 collotype plates he has figured the types or typical specimens of every species. In most cases these are new photographs made for this work as the types were being restudied.

As the work is essentially taxonomic there is no discussion of the stratigraphy, but a correlation table (following page 627) indicates the relations of the Tertiary formations in Oregon and Washington, and a tabular list of the species indicates the stratigraphic distribution of each. The third volume includes also a catalogue of 710 faunal localities and a bibliography of 886 titles.

A work so vast and painstaking has demanded much of Doctor Weaver's time over a period of several years. It is the outgrowth of more than 35 years of work on the Tertiary formations and faunas of this region. No one else could have brought to the task so rich a background of experience, and students of Tertiary faunas everywhere will feel grateful to Doctor Weaver for this great work. Since many of the species occur also in California, these volumes will be indispensable to all students of West Coast Tertiary faunas.

CARL O. DUNBAR.

Records of the Department of Mineralogy, Ceylon: Professional Paper No. 1; by D. N. Wadia. 88 pages. Ceylon Govt. Press, Colombo, 1948.—This publication is the first of a new series recently founded by D. N. Wadia, distinguished for his work on the Geological Survey of India and now Government Mineralogist of Ceylon. Four articles make up this initial number: 1, Rare Earth Minerals of Ceylon, which describes briefly their occurrence and economic importance; 2, Origin of the Graphite Deposits of Ceylon which gives a valuable account of Ceylon's principal mineral resources; 3, The Three Superposed Peneplains of Ceylon; and 4, Bibliography of Ceylon. Dr. Wadia is to be congratulated on the auspicious beginning of this new series of publications.

ADOLPH KNOPF.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Carnegie Institution of Washington Year Book No. 42. Pp. XXXII, 208. Baltimore, 1948 (The Lord Baltimore Press).—This

report for 1942-43 gives striking evidence of the vast and beneficent activities of the Carnegie Institution of Washington.

It was founded by Andrew Carnegie in 1902 and subsequently endowed by him until it now has assets exceeding $88,000,000 and is able to devote annually approximately $1,000,000 to research and publication in pure science. Its efforts are concentrated on the attempt to advance fundamental research in fields not normally covered by the activities of other agencies. Its technical staff includes 120 resident scientists plus 43 associates of whom 39 are connected with other institutions.

The present volume includes numerous short summaries of the work carried out during 1942-43 in the fields of Astronomy, Terrestrial Sciences, Biological Sciences, and Historical Research in science. CARL O. DUNBAR.

International Agreements on Conservation of Marine Resources; by Jozo Tomasevich. XI-290. Stanford, Calif. 1943 (Food Research Institute, $3.00).—That science has an increasingly dominant role to play in world politics is becoming more and more apparent. It is being gradually realized that the decisions of treaty makers and economists must have a firmer foundation than the greed of interests before a lasting and permanent pattern for international living can become established.

In this book, written by an economist, the biological background and other scientific facts underlying three international agreements between the United States and other countries concerning the conservation of seals, halibut, and salmon are presented in their true light. To thoughtful persons Tomasevich's contribution should be useful in that it forms a guide for future efforts.

The best part of the book, with reason, is the discussion of the brilliant work of the Pacific halibut program. Here beautifully conceived and firmly established biological facts which form a basis for industrial self-regulation are demonstrated. It is true that once the distinct geographical and racial characteristics of the fish were discovered the approach to the solution to the problem was simplified. But none the less, when the possible sources of international conflict are revealed in this book, it is clearly evident that the achievement is remarkable.

The participation of the United States, Russia, Japan, and Canada in the sealing convention is well known and is here adequately reviewed. The hopes and problems of the Fraser River salmon investigations (United States and Canada) are outlined, and demonstrate more clearly than in any other place the conflict of interests that inevitably arises when the conservation and management of a natural resource is involved.

It is notable that two of these problems have been solved and the other is well on its way to ultimate solution. If nations can cooperate effectively in such matters and establish the facts that underlie the problems, there would seem to be hope that many other matters can be resolved in a similar manner. H. E. WARFEL.

The Fish Gate; by Michael Graham, XIII-16-196. London, 1948 (Faber and Faber).—How far should the scientist go in educating the persons interested in the results of his own special field of work? This is a problem that perplexes the individual whose work in any way approaches what many people think to be the distinct world of practical affairs.

In this book one of the leading scientists in the field of fishery research has taken time to write, as he says, "for information, rather than advocacy" of the methods of analyzing the ills that beset the fishing industry of the British Isles.

The Fish Gate, is notable in that it follows an intricate industry from "the breakfast table, along the railway lines, through the markets at the ports, out in the fishing craft, and down to the bed of the sea." At the same time it also takes the reader aboard the research vessel, into the laboratory, and to the hearing-room where the industry and the laboratory meet for final decision.

The author has made interesting reading of the techniques of fishing, aptly describing the skill, daring and fine judgments attendant upon successful fishing in various kinds of craft. Even more outstanding, however, is the interpretation of such effort in terms of the management of the stocks of fish according to the dictates of the findings of researchers. The book is adequately summarized when the author, in the introduction, says, "I think that there cannot be too wide an application of the true scientific method to practical affairs." H. E. WARFEL.

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THE CHILHOWEE GROUP AND OCOEE SERIES OF THE SOUTHERN APPALACHIANS.

GEORGE W. STOSE AND ANNA JONES STOSE.

PART II

OCOEE SERIES.

The Ocoee series, as interpreted in this paper, forms a continuous belt which extends from the southwest end of Buffalo Mountain, Tennessee, southwestward across southern Tennessee, North Carolina, and Georgia (see Fig. 2). From its northeastern end in the Roan Mountain quadrangle it extends southwestward across the Greeneville, Asheville, Mount Guyot, Knoxville, Loudon, and Murphy quadrangles into the Cleveland quadrangle, where the type section of the Ocoee series on Ocoee River was described by Safford and Hayes. The length of the belt to the Alabama state line is about 250 miles. It varies in width from two and one-half miles at the northeast end to a maximum of 25 miles in the area southeast of Chilhowee Mountain. In the region just south of Cartersville, Georgia, the Ocoee series is nearly concealed by the Tusquitee overthrust block.

The Ocoee series forms all of the northwest border of the Great Smoky thrust block throughout its length, except at its northeast end where Lower Cambrian quartzose rocks make Buffalo Mountain. Southwest of Buffalo Mountain in the Roan Mountain quadrangle, the Ocoee series is also on the southeast border of the block. Southwestward in the Greeneville quadrangle, where the Great Smoky overthrust on the southeast side of the thrust plate passes into the early pre-Cambrian injection complex, the base of the Ocoee series is a short distance north of the southeast border of the thrust plate. Farther southwest,

the Great Smoky thrust on the southeast side of the plate in places lies at the south border of the Ocoee series and in other places lies within the injection complex.

Except in the Knoxville and Loudon quadrangles, Keith mapped all the quartzose rocks that the writers call Ocoee as Lower Cambrian. The quartzose rocks in the area lying southwest of Buffalo Mountain, beginning at a point four miles north of Erwin, are lithologically not at all like Lower Cambrian rocks but closely resemble rocks in the Ocoee series farther southwest. The writers are convinced, as was Safford, in 1869, that these rocks are not Lower Cambrian quartzites but are Ocoee.

In recent field work the writers have carefully studied the lithology of the Ocoee rocks at many places in the northeastern part of the belt. One of the best exposed sections is in the Roan Mountain quadrangle along Nolichucky River south of Embreeville, where these rocks crop out for a distance of three and one-half miles. There, the rocks consist of thin-bedded, finely arkosic quartzites with slate partings, black, graphitic slate, black quartzite with glassy, black quartz grains, dark-banded slate, and hard, dark-banded and current-bedded arkosic quartzite, in part finely conglomeratic. Mica flakes, apparently of sedimentary and not of metamorphic origin, are common on the bedding layers of these rocks. Milk-white, coarsely crystalline quartzite, pitted by large rust-stained holes, which lies at the top of the section, forms prominent cliffs above the river in Jump Hill and Stony Point. This quartzite is thick bedded but is not more than 30 feet thick; the bedding is not well-defined; and the layers thicken and thin irregularly along the strike.

The Bald Mountains, which are accessible only by foot trails, extend across the Greeneville quadrangle in a southwesterly direction and culminate in several high, short ridges or peaks, including Rich Mountain, the Big Butt, and Camp Creek Bald, which have altitudes above 4,800 feet. These peaks or "balds" are formed largely of white quartzite which makes prominent white cliffs visible from the south for many miles. In the Southern Appalachians the name "bald" is given to treeless domes because generally nothing but grasses, ferns, and stunted shrubs grow in the cold, humid climate of the high mountains. The writers found that the formation which caps the Big Butt

and adjacent part of Rich Mountain consists of two massive beds of white quartzite each about 30 feet thick, composed of granular quartzite without distinct bedding layers and pitted on weathered surfaces by rust-stained holes. The two quartzites are separated by about 200 feet of softer beds, largely dark-green, fine-grained, dense arkose and earthy-weathering argillite. The white quartzites and interbedded rocks which cap the peaks and short ridges are the youngest formation in the section on the Bald Mountains. Beneath this formation are slates with beds of dark-green, fine-grained, dense arkose, which are underlain by a crumbly, poorly assorted, coarse-grained arkose containing thin resistant beds of conglomerate which contains pebbles of milk-white quartz and black slate and thin layers of black slate. On the south side of the Big Butt, these conglomeratic beds form Gravel Knob, Green Ridge, and Snakeden Ridge. West of Gravel Knob the conglomerate contains a thin metadiabase sill, intruded parallel to the bedding. It resembles a metadiabase sill which occurs in similar beds on South Indian Creek, three miles southwest of Erwin. Below this conglomeratic arkose is a thick series of dark-banded slate and hackly-weathering, dark argillite. Still lower beds, which comprise the basal part of the Ocoee series, consist of dark, argillaceous quartzite with scattered quartz grains, black, vitreous quartzite composed of black, glassy quartz grains, and interbedded black, dense, graphitic slate. These basal beds rest in stratigraphic position on the early pre-Cambrian injection complex.

Safford[28] described the formations on the Bald Mountains as follows:

"The Big Butt . . . is . . . made up of the conglomerates and slates of the Ocoee group. The latter are pale greenish, mostly, but include some purple slates. Much of the conglomerate is coarse; pebbles as large as pigeon's eggs are abundant, but they are often larger. The general appearance of these rocks recalls portions of the Ocoee River section." The conglomerate described by Safford evidently is that which occurs on Gravel Knob adjacent to the peak of Big Butt, because no conglomerate is present in the quartzite that forms the peak.

The section exposed on the Bald Mountains closely resembles that on Nolichucky River. The white quartzites of the Big Butt and Rich Mountain are comparable in lithology and

[28] Safford, J. M.: 1869, Geology of Tennessee, p. 194.

thickness with the white quartzite that forms Jump Hill and Stony Point; in the section at both places, beds of crumbly arkose and fine, quartz conglomerate underlie the white quartzite, and beds at and near the base of the section consist of black quartzite interbedded with dense, black slate.

Near Nolichucky River and in the Bald Mountains the thinner-bedded rocks and some of the thicker beds, such as the conglomeratic arkose with black slate beds at Gravel Knob, are closely folded. The white quartzites and interbedded arkose and argillite on the Big Butt and Rich Mountain are enclosed in a narrow syncline about six miles long, and to the southwest these quartzites are enclosed in another syncline where they cap the Bald Mountains in the vicinity of Chimney Rock and Camp Creek Bald. The white quartzites and interbedded rocks near Stony Point and Jump Hill on Nolichucky River occur also in short synclines.

Because of the lithologic and structural similarity of the rocks in the two sections, and because the two areas are stratigraphically continuous, the writers consider that rocks in both areas are parts of the same series, and, like Safford, include them in the Ocoee series and not in the Lower Cambrian. These Ocoee rocks differ from Lower Cambrian rocks in the following particulars; the basal beds are black quartzite and black slate, while the basal Lower Cambrian is composed of crumbly coarse-grained arkose and thin layers of soft argillite. They lack the basalt flows which are characteristic of the Lower Cambrian Unicoi formation. The crumbly, arkosic quartzite and conglomerate that form Green Ridge and Snakeden Ridge are poorly sorted and contain black slate pebbles and interbedded black slate, and are not like any known Lower Cambrian formation. Because the white quartzites at the top are not well bedded, are lenticular, and relatively thin, and are separated by beds of arkose and argillite, they do not form long continuous ridges, which is the characteristic topographic expression of the thick well-bedded quartzites of the Lower Cambrian; instead, the quartzites at the top of the Ocoee cap isolated mountain crests.

In the Greeneville and Roan Mountain folios, Keith mapped the white quartzites and interbedded rocks of the Big Butt, Camp Creek Bald, Jump Hill, and Stony Point chiefly as Nebo quartzite. In these folios he described the Nebo as "Massive white quartzite and sandstone, coarse and fine, with a few layers

eastern part of the belt the Ocoee series is not much metamorphosed; southwest of the Asheville quadrangle, the Ocoee series in the southeastern part of the belt is highly metamorphosed. There the Hiwassee slate, Great Smoky conglomerate, Nantahala slate, and equivalent formations contain biotite, garnet, and, in places, staurolite, and the rocks of these formations include mica schist, garnet schist, staurolite gneiss, biotite gneiss, micaceous garnetiferous "graywacke," and biotitic conglomerate. Deformation in this metamorphosed belt has produced close folds, has sheared out the crests of the folds, and has developed a regional foliation commonly parallel to the layers.

Because of their limited field knowledge of the southwestern part of the belt of the Ocoee series and because of the metamorphism and close folding of the rocks there, the writers are not able to correlate the divisions of the Ocoee described above with those to the southwest. The most complete section of the Ocoee in the southwestern part of the belt occurs in the Mount Guyot quadrangle. There the basal formation of the Ocoee series overlies the early pre-Cambrian injection complex in the eastern part of the quadrangle, five miles east of Crestmont, and the higher formations of the series cap the crests of the Great Smoky Mountains southwest of Crestmont. The sequence of the formations of the Ocoee series in the Mount Guyot quadrangle, based on the mapping by Keith, and of equivalent formations in the adjacent region, is given in the following table:

Sequence of Formations of the Ocoee Series.

	Mount Guyot quadrangle (Keith)	Other quadrangles mapped by Keith
Ocoee series	Clingman conglomerate Hazel slate	Nantahala slate
	Thunderhead conglomerate Cades conglomerate	Great Smoky conglomerate
	Pigeon slate	Hiwassee slate
	Snowbird formation	Citico conglomerate Wilhite slate
	Unconformity	Unconformity
Early pre-Cambrian	Injection complex (Cranberry and Max Patch granites of Keith)	

of sandy shale and reddish sandstone" and stated that "practically all of the formation is composed of quartzite and sandstone," and gave its thickness as 200 to 900 feet. This description may apply to the Nebo quartzite of well-established Cambrian age which makes foothills along the northwest side of the Bald Mountain and in Cherokee Mountain, which is the northeastward continuation of these foothills, where the Nebo is a thick, massive, and well-bedded quartzite that forms long, linear ridges. The Cambrian quartzite in these ridges does not at all resemble in lithology, thickness, or topographic expression the white quartzites and interbedded rocks that form the Big Butt, Jump Hill, and Stony Point to which also Keith applied the name Nebo.

The thin series of slate and fine-grained, dense arkose beneath the white quartzite on the Big Butt Keith mapped as Nichols slate, and the underlying conglomeratic arkose and black slate, which forms Gravel Knob and Snakeden Ridge, he called Cochran conglomerate. The Cochran conglomerate in the established Cambrian section in Cherokee Mountain is a hard, white, vitreous, well-bedded quartzite, in part current bedded, and thin-bedded quartzite with interbedded gray slate. These characteristic Cambrian features are not present in the conglomeratic arkose of Gravel Knob, Green Ridge, and elsewhere in the Bald Mountains to which Keith applied the name Cochran.

The thick series of dark-banded slate and hackly-weathering, dark argillite, beneath the so-called Cochran conglomerate of Green Ridge, Keith mapped as Hiwassee slate. The black, argillaceous quartzite, vitreous, black quartzite, and black slate at its base Keith mapped as Snowbird formation, assigned them to the basal Lower Cambrian, and regarded them as equivalent to the Unicoi formation. These basal beds are lithologically unlike the Unicoi formation or any other formation known in the Lower Cambrian. The names Hiwassee slate and Snowbird formation are derived from outcrops of Ocoee rocks and not outcrops of Cambrian rocks, and therefore they may be properly applied to formations in the Ocoee series but not to Cambrian rocks.

The Ocoee series in the northeastern part of the belt differ from the Ocoee series farther southwest mainly in degree of metamorphism and intensity of compression. In the north-

The writers have attempted to determine the equivalence of these formations of the Ocoee series with formations of the Ocoee to which Keith later gave Cambrian names. From their field observations they conclude that Keith mapped as Nebo quartzite the highest white quartzite in the Ocoee series, which probably is the equivalent of the Clingman conglomerate in the Mount Guyot and Knoxville quadrangles; that he mapped as Cochran conglomerate, conglomeratic arkosic quartzite, which may be part of his Great Smoky, Thunderhead, and Cades conglomerates. The slates and argillites and the underlying ferruginous quartzite, near the base of the Ocoee, Keith called Hiwassee slate and Snowbird formation in regions where he used Cambrian names for the higher formations. In Fig. 2 the writers show the generalized subdivisions of the Ocoee series throughout its extent, based on Keith's maps and interpreted in terms of the Ocoee section as stated above.

Three areas of rocks that resemble the Ocoee series lie outside the Great Smoky overthrust block. One small area at the west border of the Roan Mountain quadrangle, eight miles southwest of Erwin, consists of black quartzite and black graphitic slate and lies on the injection complex of the Holston Mountain block. In the Asheville folio two areas of metamorphosed sedimentary rocks, which Keith mapped as Hiwassee slate, Great Smoky conglomerate, and Nantahala slate, may belong in the Ocoee series. He correlated the two upper formations respectively with the Cochran conglomerate and Nichols slate, and shows the underlying Hiwassee slate resting for the most part on granites of Archean age.

AGE OF THE OCOEE SERIES.

The age of the Ocoee series has not previously been established. It has been called Eozoic by Safford; probably Algonkian by Hayes; age unknown, Silurian, Paleozoic, and Lower Cambrian by Keith; Cambrian by La Forge and Bayley; and Cambrian in part and pre-Cambrian in part by the Georgia Geological Survey. On the Geological Map of the United States[29] and in a report published by the junior author,[30] the Ocoee series was called in part Cambrian and in part pre-

[29] Geological map of the United States; U. S. Geological Survey, 1933.

[30] Jonas, A. I.: 1932, Structure of the metamorphic belt of the southern Appalachians: Amer. Jour. Sci., 5th Ser., Vol. 24, p. 240.

Cambrian. Keith's early evidence that the Ocoee series is of late Paleozoic age is nullified by the establishment of thrust relations of the Ocoee series to the Paleozoic rocks in the Mount Guyot and Knoxville quadrangles.

The two main reasons why the position of the Ocoee series in the stratigraphic column has not been fixed with certainty are that no fossils have been found in the series; and that along the northwest border, the belt of Ocoee rocks is everywhere separated from rocks of established Paleozoic age by a thrust fault, the Cartersville overthrust in Georgia and the Great Smoky overthrust in Tennessee. In the Roan Mountain and Greeneville quadrangles, however, the writers have found evidence of the age of the Ocoee series. On the southwest slope of Buffalo Mountain the basal beds of the Unicoi formation of Lower Cambrian age overlie the Ocoee series. Although the writers did not find an actual contact of these Lower Unicoi beds and the rocks of the Ocoee series, the two series appear to be in stratigraphic sequence and not in fault relation. The Unicoi formation in Buffalo Mountain consists of the three characteristic divisions; coarse-grained arkosic quartzite at the base; medial basalt flows; hard white quartzite in the upper part. The coarse-grained, arkosic quartzite at the base overlies finely laminated, rust-specked quartzite which is typical of the Ocoee series. In the southeastern part of the Greeneville quadrangle black quartzite interbedded with black graphitic slate, which Keith mapped as Snowbird formation, forms the base of the Ocoee series and rests on the injection complex of early pre-Cambrian age. There the injection complex consists, in large part, of the Cranberry granite of Keith and in part of biotite augen gneiss similar to a gneissic rock which elsewhere Keith has called Max Patch granite. In the Asheville quadrangle, south of the Hot Springs window, and in the eastern part of the Mount Guyot quadrangle, the Snowbird formation rests on the injection complex. The strike of the basal beds of the Ocoee series in these areas is discordant with the structures of the rocks of the injection complex. The injection complex is highly metamorphosed and the Ocoee series is not, and the two series are separated by a marked structural and erosional unconformity.

Evidence has been given to show that the Ocoee series overlies unconformably the injection complex of early pre-Cambrian

age and is much younger than the injection complex; that the rocks of the Ocoee series are distinctly different in lithologic character from the Lower Cambrian rocks, and its mappable units differ from those of the recognized Lower Cambrian formations; that in the few places where the Lower Cambrian and Ocoee rocks are known to occur in contact and not in fault relation, the Ocoee appears to lie stratigraphically beneath basal beds of the Unicoi formation of Lower Cambrian age, and to be older than Lower Cambrian. The Ocoee series, therefore, is believed by the writers to be of late pre-Cambrian age.

CORRELATION OF THE OCOEE SERIES.

The Ocoee series is here correlated with the Lynchburg gneiss and its equivalents, with the Mount Rogers volcanic series, and with the Talladega series. The Lynchburg gneiss and its equivalents in northern Virginia lie on the east limb of the Catoctin Mountain-Blue Ridge anticlinorium to a point about 20 miles southwest of Lynchburg. Southwest of that point, in Virginia and North Carolina, the Lynchburg gneiss has been thrust northwestward on the Gossan Lead thrust fault over the early pre-Cambrian injection complex and overlying Lower Cambrian rocks of the Holston Mountain block.

The Lynchburg gneiss at its type locality at Lynchburg, Va.,[31] is composed of quartzose, garnetiferous mica gneiss and mica schist, in places graphitic. Northeast of the type locality the Lynchburg gneiss merges into a less-metamorphosed series of coarse-grained arkose, quartzites, and graphitic slate. In the Warrenton quadrangle the series has been called the Fauquier formation by Furcron,[32] who described it as composed of black, graphitic slate and quartz-mica schist.

The Rockfish conglomerate, which lies at the base of the Lynchburg gneiss at many places, overlies the early pre-Cambrian injection complex and contains cobbles and pebbles derived from the complex. In northern Virginia where the conglomerate is absent in places, coarse arkose lies at the base of the series. In the Gossan Lead overthrust block in southern Virginia and in North Carolina the Lynchburg gneiss is more

[31] Jonas, A. I., and Stose, G. W.: 1939, Op. cit. Amer. Jour. Sci., Vol. 237, pp. 588-590.

[32] Furcron, A. S.: 1939, Geology and mineral resources of the Warrenton quadrangle, Va.: Virginia Geol. Surv. Bull. 54, pp. 37-41.

highly metamorphosed than in central and northern Virginia, and is a closely folded series of biotite-quartz gneiss and schist, in places garnetiferous and staurolite bearing. In part it is a spangled muscovite-garnet schist, biotite quartzite containing quartz grains, and graphitic and ferruginous quartzose mica gneiss and schist. Northeast of Lynchburg, on the east limb of the Catoctin Mountain-Blue Ridge anticlinorium, the Lynchburg gneiss, Fauquier formation, and equivalent rocks underlie the Catoctin basalt. On the west limb of the anticlinorium in northern Virginia, a series of tuffaceous and arkosic sediments[33] underlie the Catoctin basalt and overlie the injection complex. The writers have named this formation the Swift Run tuff.[34]

The Loudon formation and Weverton quartzite of Lower Cambrian age overlie the Catoctin basalt on both limbs of the anticlinorium, and in places the Lower Cambrian rocks overlap onto the injection complex. The Catoctin basalt and the underlying Swift Run tuff and Lynchburg gneiss are older than the Lower Cambrian and younger than the injection complex and are of late pre-Cambrian age. The Ocoee series, which resembles the Lynchburg gneiss in lithology and in variability of metamorphism, and occupies a similar stratigraphic position, is therefore of the same relative age as the Lynchburg.

The Fauquier formation and the Lynchburg gneiss in Virginia and the Lynchburg gneiss in North Carolina are intruded by gabbro and peridotite which have been metamorphosed to hornblende gneiss and serpentine. These intrusions and related metadiabase dikes which cut the injection complex in northern Virginia are genetically related to the Catoctin basalt and are of late pre-Cambrian age. In the northeastern part of the belt the writers have found a few thin sills or dikes of diabase in the Ocoee series. The diabase resembles the intrusions just described and is probably of the same age.

The Mount Rogers volcanic series[35] lies on the northwest limb of the Elk Creek anticline in southwestern Virginia and northern North Carolina and Tennessee. In Virginia the vol-

[33] Jonas, A. I., and Stose, G. W.: 1939, Op. cit. Amer. Jour. Sci., Vol. 237, pp. 582–589.

[34] Stose, G. W., and Jonas, A. I.: Pre-Cambrian and Lower Cambrian quartzose rocks of southeastern Clarke County, Virginia: Virginia Geol. Surv. (Report transmitted for publication.)

[35] Jonas, A. I., and Stose, G. W. 1939, Op. cit., Amer. Jour. Sci., Vol. 237, pp. 590–591.

canic series extends from a point eight miles northwest of Independence southwestward for 30 miles to the State line. The volcanic series, which is 1,000 feet or more thick, is composed of a thick series of rhyolite flows underlain by tuff, arkose, and basalt flows, and overlain by a series of red tuff and arkose. The Mount Rogers volcanic series is of late pre-Cambrian age because it overlies and is structurally discordant, with the injection complex and is overlain by the Lower Cambrian Unicoi formation. A network of rhyolite and diabase dikes, related to the flows of the volcanic series, penetrates the injection complex of the Elk Creek anticline but does not cut the overlying Lower Cambrian rocks. The writers correlate the Mount Rogers volcanic series with the Catoctin basalt, Swift Run tuff, Lynchburg gneiss, and associated intrusives, because they have similar stratigraphic relations to older and younger rocks and are of the same relative age. Although the Ocoee series contains no extrusive rocks, such as make up a large part of the Mount Rogers volcanic series, the writers correlate the Ocoee series with the Mount Rogers series on the basis of their similar stratigraphic position and age and the resemblance of arkosic beds present in both series.

In northwestern North Carolina and in Georgia, the Ocoee series contains intrusive rocks, largely granite, which are more widespread in the southeast part of the belt of the Ocoee series. The largest area of granite is a narrow band which extends from a point seven miles south of Crestmont southwestward for about 20 miles. (See Fig. 2.) This granite area is shown in part on Keith's manuscript maps of the Mount Guyot and Cowee quadrangles. Where seen by the writers north of Whittier, North Carolina, it is a muscovite-biotite granite which intrudes, injects, and replaces rocks of the Ocoee series. W. S. Bayley describes the Salem Church granite, west of Tate, as intrusive in the Hiwassee slate, which is saturated near the intrusive contact with granitic material. Crickmay in his paper on the Talladega series[36] states that the Corbin granite, lying east of Cartersville, is intrusive into and younger than the "Talladega schists," and that in places the granite penetrates the schists in streaks and lenses. The granites mentioned above are similar in character to the Whiteside granite of Keith,[37]

[36] Crickmay, G. W.: 1936, Op. cit., Geol. Soc. Amer. Bull., Vol. 47, p. 884.
[37] Keith, Arthur: 1907, U. S. Geol. Surv., Geologic Atlas, Pisgah folio (No. 147), p. 4.

which intrudes the rocks of the Tusquitee overthrust block in wide areas in North Carolina. The writers agree with Keith's statement in the folio, that they are in large part free from metamorphism and may be as late as Carboniferous in age.

The Ocoee series in Cohutta and Fork Mountains, in the Dalton quadrangle, Georgia, contains talc deposits. In his paper quoted above, Crickmay says that the talc was formed from the alteration of metaperidotite. La Forge[38] described a gabbro-like dike rock in the Great Smoky formation near Copperhill, Georgia. He says that it is somewhat deformed but is probably of late Paleozoic age, and he correlated it with the ultramafic rocks that occur in the Dalton quadrangle. Laney[39] states that the gabbro near Copperhill was intruded into the Great Smoky formation as sills prior to folding, and that the original minerals are altered. In method of intrusion and the alteration of its minerals, the gabbro near Copperhill resembles the metadiabase which occurs in concordant sills in the Ocoee series in the northeast part of the belt. It is possible that the gabbro and ultramafic rocks in Georgia also are of late pre-Cambrian age.

Southwest of Cartersville, Georgia, the Ocoee series extends across western Georgia and passes into Alabama, where Smith[40] named it the Talladega series from exposures in the Talladega Hills, Alabama. In Alabama the Talladega series lies southeast of the Great Valley in a belt eight to 22 miles wide. The Talladega series is thrust northwestward on the Cartersville fault over Paleozoic rocks of the Great Valley, and is cut off on the southeast by the Tusquitee overthrust. (See Fig. 2.)

Butts,[41] who has mapped a large part of the Talladega series in Alabama, called it the Talladega slate. He states (p. 60) that it is the consensus of opinion that the Talladega slate of Alabama includes the equivalent of the Ocoee series of Safford in Tennessee. He describes the Talladega as consisting of slate and sericitic phyllite with beds of conglomerate, quartzite, lime-

[38] La Forge, Laurence: 1918. Ellijay folio, Op. cit., p. 8.

[39] Emmons, W. H., and Laney, F. B.: 1926, Geology and ore deposits of the Ducktown mining district, Tennessee: U. S. Geol. Survey Prof. Paper 139, p. 22.

[40] Smith, E. A.: 1936, A general account of the character, distribution, and structure of the crystalline rocks of Alabama and the mode of occurrence of the gold ores: Ala. Geol. Surv. Bull. No. 5, 108–180.

[41] Butts, Charles: 1926, Geology of Alabama, The Paleozoic rocks of Alabama: Ala. Geol. Surv. Spec. report 14, pp. 49–61.

stone, marble, chert, and graphitic phyllite. The writers agree with Crickmay[42] that "In view of the diverse lithology, the designation, series, is preferred to that of Talledega slate." Butts said also that "The Talladega slate represents a time beginning possibly in the Algonkian period and extending as now known into the Paleozoic era." He based this statement on the presence of fossiliferous Jemison chert of Devonian age and of fossiliferous Erin shale of Carboniferous age within the area of Talladega slate, which he regarded as part of the series. It has been shown,[43] however, that the Erin shale is not an integral part of the Talladega series but is exposed in a window in the overthrust block. It seems probable to the writers, also, that the Jemison chert has a similar relation to the Talladega series and is not a stratigraphic part of the series and that the presence of Paleozoic fossils in the Erin shale and the Jemison chert has no bearing on the age of the Talladega series.

The most convincing evidence of the age of the Talladega series is found in the Columbiana quadrangle, Alabama, where Butts[44] states that the Lower Cambrian Weisner formation "is apparently in unconformable relation to the Waxahatchee slate [of the Talladega series] below, and conformably underlies the Shady dolomite above." These relations are shown where the Weisner formation, in a northeastward-plunging syncline, forms the horseshoe-shaped Columbiana Mountain. At the contact of the Weisner formation and the Waxahatchee slate, the Brewer phyllite and Wash Creek slates, which Butts regards as formations of the Talladega series younger than the Waxahatchee, are absent. The pre-Cambrian age of the Talladega series in Alabama thus seems to be clearly established.

The Talladega series of Alabama is stratigraphically continuous northeastward into the Ocoee series of Safford and Hayes in Georgia and Tennessee. The writers correlate the Talladega series of Alabama with the entire belt of the Ocoee series as defined in this paper. In Georgia and northeastward, Crickmay restricts the name Ocoee series to the rocks in the

[42] Crickmay, G. W.: 1936, Idem., p. 1872.

[43] Jonas, A. I.: 1932, Structure of the metamorphic belt of the Southern Appalachians: Amer. Jour. Sci., 5th series, Vol. 24, pp. 228-243.

Park, C. F.: 1935, Notes on the structure of the Erin shale of Alabama: Wash. Acad. Sci. Jour., Vol. 25, pp. 276-279.

[44] Butts, Charles: 1940, U. S. Geol. Surv. Geologic Atlas, Montevallo-Columbiana folio (No. 266), p. 4.

northwestern part of the belt, which he considers to be of Lower Cambrian age, and correlates the Talladega series, which he considers to be of pre-Cambrian age, with rocks in the southeastern part of the belt. He separated the "Talladega series" from the rocks he called Ocoee by a thrust fault which enters the highland belt at a point ten miles northeast of Chatsworth and 40 miles northeast of Cartersville, and he applied the name Cartersville to this fault. The Cartersville fault, as defined by Hayes,[45] follows the western and northwestern border of the Ocoee series all across northern Georgia and into Tennessee to the northeast edge of the Cleveland quadrangle. The writers believe that the original definition of this fault should be adhered to. They propose the name Cohutta overthrust for the minor fault which branches from the Cartersville thrust east of Chatsworth, passes through the Cohutta Mountains, and apparently dies out near Hiwassee River in Tennessee. On the geologic map of the United States published by the U. S. Geological Survey in 1933, a fault is shown in the position indicated by Crickmay in Fig. 1 of his report. It separates rocks on the southeast that were believed to be of pre-Cambrian age from rocks on the northwest that were at that time regarded as Cambrian. The junior author[46] of this paper also recognized this fault within the highland belt but did not name it. The fault marks a zone in which metamorphic minerals in the rocks have been degraded from higher to lower rank, and in which folded structures have been deformed. The junior writer at that time believed that on this fault pre-Cambrian rocks were thrust northwest over Cambrian rocks. On the basis of later field work on the Ocoee series, the writers now believe that the rocks on both sides of the Cohutta thrust are pre-Cambrian in age and are part of the Ocoee series, and that the thrust occurs along a movement zone within the Ocoee series.

Dual metamorphism and close folding, with partial obliteration of original structures and folding of schistose planes, were noted by La Forge in the rocks of the Ellijay quadrangle. Crickmay in his report (pp. 1387-1390) described in detail these features in the Talladega series as restricted by him to the southeastern part of the Ocoee belt, and stated that the rocks he called Talladega contain a folding and metamorphism

[45] Hayes, C. W.: 1891, Op. cit., Geol. Soc. Amer. Bull., Vol. 2.
[46] Jonas, A. I.: Idem.

not present in the Ocoee rocks of the northwestern part of the belt, which he considered to be Cambrian, and that the first folding and metamorphism occurred in pre-Cambrian time. He presented these structural and metamorphic features as the main argument for the pre-Cambrian age of the rocks of the southeastern part of the belt. Hayes noted variability of metamphorism also in the rocks of the Ocoee series along the border of the Cartersville thrust in Georgia and Tennessee, where deformation of metamorphic structures produced "curly" slates similar to the "bullshead" slates which Crickmay restricts to the pre-Cambrian rocks of the southeastern part of the belt.

From evidence obtained in their recent field work, the writers believe that the Ocoee series, in the northeastern part of the belt, was little folded or metamorphosed in pre-Cambrian time. In the Roan Mountain, Greeneville, and Asheville quadrangles neither the Ocoee nor the Lower Cambrian quartzose rocks are much metamorphosed, and also in that area the Ocoee series shows no evidence of a folding that is not shared by the Lower Cambrian rocks. The writers ascribe the major folding and overthrusting of both series to late-Paleozoic deformation. They ascribe also much of the metamorphism of the Ocoee series in southern North Carolina and Tennessee to the regional metamorphism during the late-Paleozoic. They suggest also that some of the metamorphism may have been produced by hot solutions given off by the late-Paleozoic granitic masses which were intruded into the Ocoee series in that region. The change of metamorphic minerals to minerals of lower metamorphic rank and the deformation of folded structures in the Ocoee series occur largely along the Great Smoky, Cartersville, and Cohutta overthrusts and appear to be related to the strong differential movement of the rocks in these thrust zones. They correlate with the Talladega series of Alabama both the southeastern part of the belt in Georgia, Tennessee, and North Carolina, called Talladega by Crickmay and the northwestern part which contains the type locality of the Ocoee series of Safford and Hayes. The Ocoee series as defined in this paper is lithologically similar and stratigraphically continuous with the Talladega series of Alabama and both series are late pre-Cambrian in age.

SUMMARY OF CONCLUSIONS.

The evidence presented in this paper seems to warrant the following conclusions. The Ocoee series is a definite stratigraphic unit which extends from the southwest end of Buffalo Mountain, Tennessee, southwestward across Tennessee, North Carolina, and Georgia, covering essentially the area called Ocoee by Safford in Tennessee and by Hayes in Tennessee and Georgia. The Ocoee series is distinct in lithology from the Lower Cambrian quartzose rocks of southern Virginia and northern Tennessee and from the Lower Cambrian Chilhowee group and it is not of Cambrian age but is of late pre-Cambrian age. The thick series of coarse-grained quartzose rocks composing the Great Smoky Mountains, therefore, is not a great local expansion of Lower Cambrian quartzose rocks, as heretofore believed. Because of the difference in age and lithology, none of the formations of the Ocoee series is equivalent to formations of the Chilhowee group or to any other formations of known Lower Cambrian age. Serious confusion of the stratigraphic sequence, the misapplication of formation names, and errors in structural interpretation of the region have resulted from miscorrelation of formations of the Ocoee series with Lower Cambrian formations by some of the previous workers in the region. Formations mapped as Hesse quartzite, Murray shale, Nebo quartzite, Nichols slate, and Cochran conglomerate, that do not occur in a section of well-defined Lower Cambrian sequence, have no stratigraphic value.

The late pre-Cambrian age of the Ocoee series is established by the fact that the Ocoee series, in the northeastern part of the Great Smoky thrust slice, underlies Lower Cambrian Unicoi formation and overlies the injection complex of early pre-Cambrian age, and also from the fact that, in Alabama, the Talladega series, which is a southward continuation of the Ocoee series, is uncomformably overlain by the Lower Cambrian Weisner quartzite. The Ocoee and the Talladega series are equivalent in age to the Mount Rogers volcanic series of southern Virginia and northern North Carolina and Tennessee, the Lynchburg gneiss of central and northeastern Virginia, and the Fauquier formation, Catoctin basalt, and Swift Run tuff of northern Virginia.

WASHINGTON, D. C.

FOSSIL GAVIALS FROM NORTH INDIA.

RICHARD SWANN LULL.

ABSTRACT. An apparently new species of gavial is described from the Dhok Pathan, Middle Siwalik of the Punjab, India, together with some discussion of the apparent evolutionary changes which these crocodiles have undergone as shown by their fossil remains.

INTRODUCTION.

THE Yale North India Expedition of 1932 collected vertebrate fossils largely in Punjab, through the immediate labors of Dr. G. Edward Lewis. Among other interesting forms which came to light were portions of at least three gavials, one a very fine skull and jaws, but lacking the anterior two thirds of the rostrum and the others, two cranial rostral fragments, widely separated in time. These specimens form the basis for this paper, the skull particularly being worthy of record and description.

The material under consideration consists therefore, first of the skull of a huge gavial bearing the Field Number 19, Cat. No. Y.P.M.VP-3226, occurrence Middle Siwalik, Dhok Pathan. Locality south of the Soan River, east of the Ghambhir Kas and seven and one-half miles east-by-south of the village of Dhok Pathan. (Lat. 33° 2′ N. Lon. 72° 28′ approximate.) Second a fragment of the cranial rostrum from the anterior nares back to just beyond the fifth pair of maxillary teeth. This portion bears the Field Number 79, Cat. No. Y.P.M.VP-3227. Occurrence, Upper Middle Siwalik, Bhandar, now considered a local facies development of the Dhok Pathan. Locality one and one-half miles west of the village of Bhandar and three-fourths of a mile west of the Bhandar River (Lat. 32° 50′ N., Lon. 73° 18′ E. approximate). The third specimen, Field No. 99, Cat. No. Y.P.M.VP-3228, is also a portion of the rear of the cranial rostrum including 7 or 8 teeth or their alveoli and portions of the nasal, palatal and maxillary bones. Occurrence, Lower Upper Siwalik, Tatrot. Locality about two miles slightly north of east of the town of Padhri. (Lat. 73° 53′ N., Lon. 32° 20′ E. approximate.)

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DESCRIPTION OF SPECIES.

Gavialis lewisi[1] sp. nov.

Material: The holotype Y.P.M.VP-3226, is the finely preserved skull of a large gavial, intact from the rear forward to the anterior termination of the palatine bones, with an equivalent length of the mandible. A slender stapes was also found within matrix near the external auditory meatus. The anterior end of the muzzle, however, which so often shows diagnostic characters, is lacking, nor is there sufficient of the rostrum to determine whether any degree of curvature was present—also a distinctive character. Little if any crushing or other distortion of the specimen is in evidence.

Occurrence: The position of this species in the geologic column is about midway in the known distribution of the genus *Gavialis*, having been found in the Dhok Pathan formation which is Middle Siwalik; Middle Pliocene.

Locality: South of the Soan River not far from the village of Dhok Pathan which gives its name to the horizon.

Specific characters:

Cranium: Dorsal aspect (Fig. 1).

Profile in front of the orbits is abruptly concave, and the anterior rim of the orbits strongly everted. Orbits about equal in size the supratemporal fenestrae, but the interorbital (frontal) bar is about four times the width of the parietal bar, separating supratemporal fenestrae. The latter are subtriangular with rounded angles and are slightly longer than broad. The quadrates and quadratojugal bones are widely expanded.

Palatal aspect: (Fig. 2) The palatal vacuities are elongated oval, with the palatal bar which separates them widening strongly toward the front, instead of being parallel sided as in the existing species. The ventral aspect is marked by deep concavities especially in the region of the pterygoid bones. There is also a slight longitudinal depression running the length of the combined palatine bones. One very distinctive feature is the great relative width of the internal narial aperture, which is separated from the general surface of the pterygoids by a high, thin, transverse ridge, which forms part of a parapet entirely surrounding the aperture except at the outer ends.

A characteristic gavial feature lies in the globular swelling

[1] Named in honor of its discoverer, G. Edward Lewis.

of the pterygoid bones that arise on either side of the midline and are clearly visible both from above, through the orbits and below through the palatal vacuities. In the present specimen, an aged individual, these swellings are huge and somewhat irregular in shape, but suggestive of goose eggs in size. They

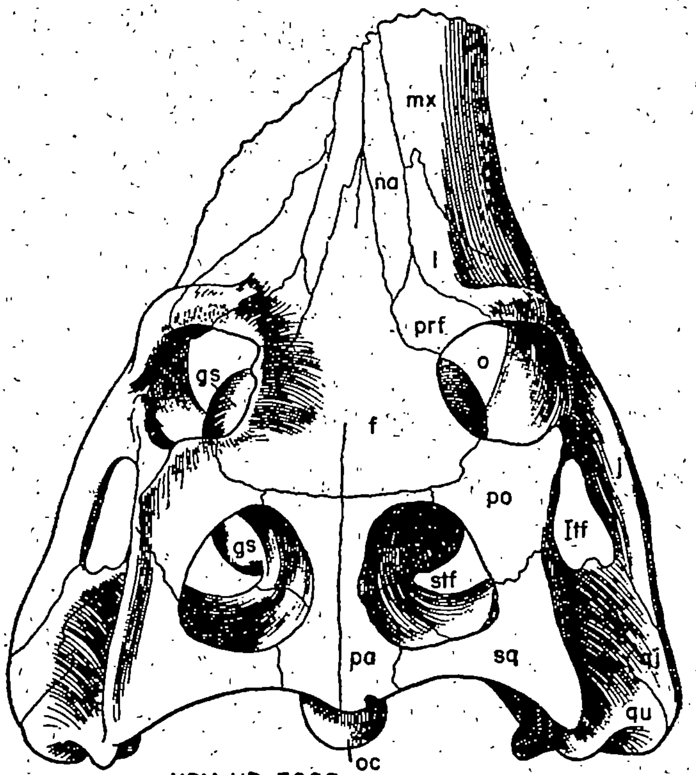

Fig. 1. *Gavialis lewisi* n. sp. Dorsal aspect of skull. No. Y.P.M. VP-3226. One-fourth natural size.

are very thin-walled and the cavities within communicate with the narial canal.

The alveolar margins of the maxillae are beveled, but there is no sign of interdental pits to receive the summits of the

List of bones: bo, basioccipital; ect, ectopterygoid; exo, exoccipital; f, frontal; gs, globular swelling of pterygoid; Ina, internal narial aperture; Itf, infratemporal fenestra; j, jugal; qu, quadrate; qj, quadratojugal; l, lacrimal; max, maxilla; na, nasal; o, orbit; oc, occipital condyle; pa, parietal; pal, palatine; pv, palatial vacuities; po, postorbital; prf, prefontal; pt, pterygoid; so, supraoccipital; sq, squamosal; Stf, supratemporal fenestra.

Drawn by Nelda E. Wright.

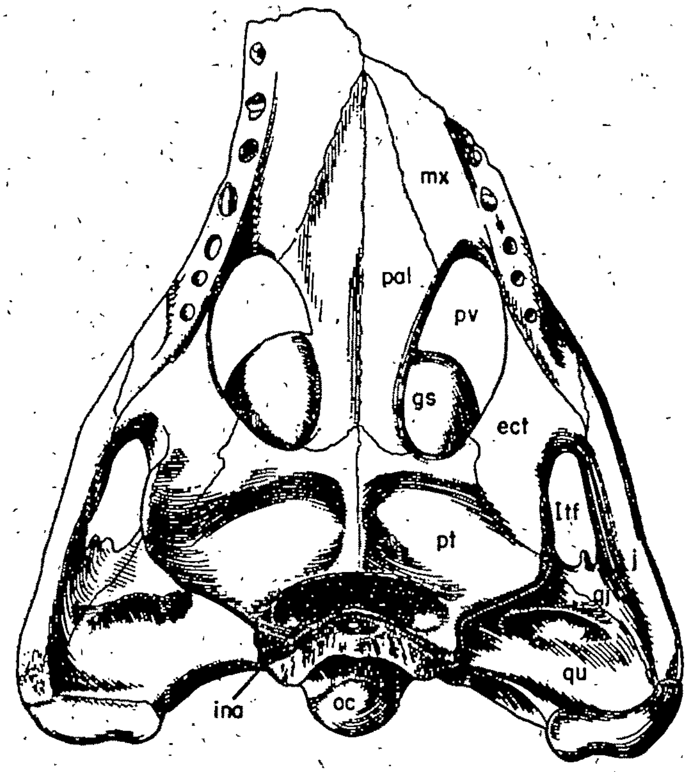

Fig. 2. *Gavialis lewisi* n. sp. Palatal aspect of skull. One-fourth natural size.

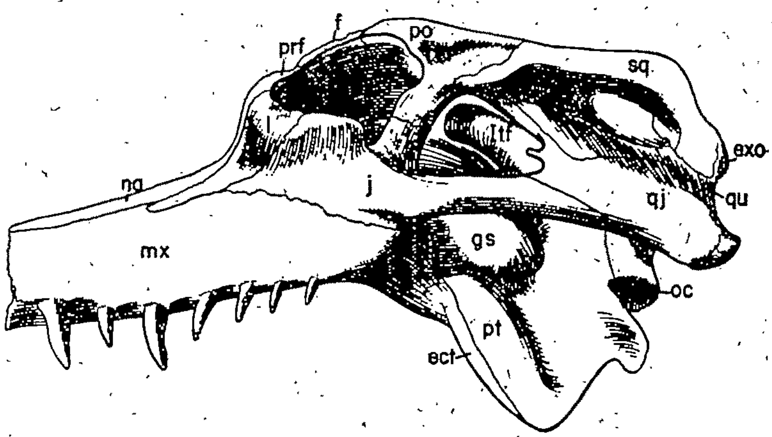

Fig. 3. *Gavialis lewisi* n. sp. Lateral aspect of skull. One-fourth natural size.

mandibular teeth. The teeth, of which six were evidently present on either side behind the anterior termination of the palatine bones, are fairly large, and though somewhat variable in size, are separated by interspaces about equal in length to the fore and aft diameter of the teeth themselves. The tooth crowns are somewhat recurved and the principal carinae lie at an angle of about 45° with that of the tooth-row. There is little or no trace of minor carinae on the surface of the crown. The mandible shows no distinctive characters other than the

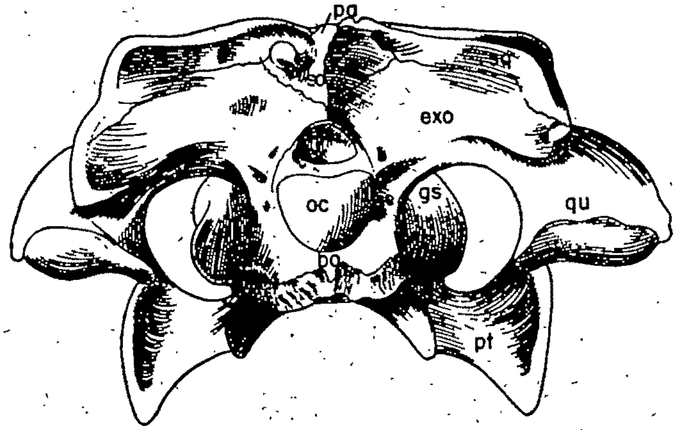

Fig. 4. *Gavialis lewisi* n. sp. Posterior aspect of skull. One-fourth natural size.

number of teeth behind the symphysis, apparently five, and the evident presence of interdental pits in the extreme rear. The mandibular teeth are strong and are curved inward, otherwise they correspond with those in the maxilla.

A second specimen is Cat. No. Y.P.M.VP-3227, a fragment of cranial rostral also from the Dhok Pathan, although found some miles away may pertain to the same species, for while the tooth crowns are missing, the size of their roots and their spacing approximately agree with the holotype. The portion preserved consists of that part of the premaxillae from the rear margin of the anterior nares, flanked by the anterior part of the maxilla on either side, sufficient to include the alveoli of five teeth. The alveoli of three teeth occupy a space about equal to the breadth of the rostrum. A slight upward curvature is present and in all probability the muzzle showed the characteristic expansion, but this cannot be proved from the specimen itself.

The premaxillae extend backward on the ventral aspect to the rear of the fourth maxillary teeth—on the dorsal aspect to the fifth, as in the existing gavial.

DISCUSSION.

Thus far eight species and one variety of gavials have been described, all from India and the adjacent lands. With the obvious exception of the existing form *G. gangeticus*, the type material, is always incomplete, that of *G. browni* being the best preserved on record. And as usual with material of this sort, corresponding diagnostic portions of the several types are not always present, which renders a complete picture of each form and a precise comparison of the species impossible. Thus of *Gavialis hysudricus* there is present only the hinder part of the cranium and the greater part of the rostrum; of *Gavialis curvirostris* portions of three crania and part of the rostrum; of *Gavialis leptodus*, the hinder part of the rostrals with little of the cranium; of *Gavialis pachyrhynchus*, the forward extremity of the cranial rostrum only; of *Gavialis browni*, skull lacking the premaxillae and mandible; of *Gavialis curvirostris* var. *gajensis*, cranial rostral from orbits forward and the mandibular symphysis; of *Gavialis breviceps*, a mandibular symphysis and cranial rostral of another individual.

On these as a basis the following brief diagnoses may be given:

Gavialis gangeticus (Gmelin) Recent to Siwalik?
No interdental pits in maxillae.

Teeth $\frac{27\text{-}29}{25\text{-}26}$. Profile abruptly depressed in front of orbits, anterior orbital border prominent, orbits about equal the supratemporal fenestrae, widely separated, frontal bar deeply concave. Supratemporal fenestrae relatively large, broader than long, and separated by a narrow parietal bar averaging about one-fifth the interorbital width. Length of palatal vacuities about twice their breadth, inner margins nearly parallel. These proportions vary somewhat with age. Internal nares of average width, without anterior parapet.

Tooth diameter equal to or greater than the interspace. Second premaxillary teeth relatively small.

Rostral with slight upward curvature and expanded extremity.

TABLE I.

Geological Distribution.					Geographical
Recent				Gavialis gangeticus (Existing species)	India Burma
PLEISTOCENE	Upper	Upper	(Tawi) Pinjor	Fossil species Gavialis leptodus	"True Siwalik Hills," Eastern Punjab
	Lower	Siwalik	Tatrot	Gaviolis sp. indet.	N. of Salt Range W. of Tatrot 2 miles N. of E. of Padhri, Punjab
PLIOCENE	Upper	Middle	Dhok Pathan	Gavialis hysudricus Gavialis lewisi n. sp.	Siwalik Hills, Possibly Perim Island. Near Dhok Pathan N. of Salt Range, Punjab
	Lower	Siwalik	Nagri	Gavialis browni	1 mile S. of Nathot N. of Salt Range, Punjab
MIOCENE	Upper	Lower	Chinji	Gavialis curvirostris Gavialis pachyrhynchus	Laki Hills, Sind Laki Hills, Sind
	Middle	Siwalik	Kamlial		
	Lower		Gaj	Gavialis curvirostris var gajensis Gavialis breviceps	Bugti Hills, Baluchistan

Gavialis leptodus Falconer and Cautley.
Level: Upper Siwalik?—Pleistocene.
Known from hinder part of rostral only.

With interdental pits in maxillae to receive apices of lower teeth, in line with tooth row. Teeth proportionately smaller than usual; three alveoli equalling from one-third to one-half the rostral diameter, cranial rostrum of greater width and flatness, especially at mid-length; alveolar border slightly beveled.

Gavialis hysudricus Lydekker.
Level: Upper Siwalik (Dhok Pathan), Pliocene.
Known from part of cranium and the greater part of cranial rostrum.

No interdental pits.

Teeth $\frac{22}{?}$ agree in size with those of *gangeticus*.

Profile depression greater and much more sudden than in *gangeticus*. Anterior orbital border prominent, thickened. Frontal bar deeply concave, supratemporal fenestrae relatively small; broader than long, separating parietal bar more than half the width of the frontal bar between the orbits; about one-fifth in *gangeticus*. Palatal vacuity unrecorded. Greater expansion of the jugal-quadratojugal region than in *gangeticus*. Relative size and spacing of teeth about equal to those of *gangeticus*. Space of three alveoli equals about three-fourths the rostral width.

Gavialis browni Mook.
Level: Lower Middle Siwalik (? Nagri), Lower Pliocene.
Known from skull and cranial rostral—premaxillae and mandible missing. Skull massive.
No interdental pits.

Teeth, $\frac{20}{?}$, relatively strong and far apart. Three alveoli equal about three-fourths the width of rostral.

Profile not abruptly depressed. This may be more apparent than real, due to post-mortem crushing. Anterior border of orbit not strongly everted. Orbits about equal in size to that of the supratemporal fenestrae. Orbits relatively close together, frontal bar almost twice the width of the parietal. Supratemporal fenestrae large, wider than long. Palatal vacuities long, narrow, inner margins parallel.

Gavialis curvirostris Lydekker.
Level: Lower Siwalik (? Chinji), Upper Miocene.
Known from three imperfect crania and parts of the rostrum. Size and spacing of teeth about as in *gangeticus*. Space of three alveoli equals more than half rostral width.
With interdental pits, mesad of tooth row.

Profile not depressed in front of orbit, anterior border of orbit not everted. Width of interorbital (frontal) bar about as in *gangeticus*—also true of the supratemporal fenestrae and parietal bar. Palatal vacuities unrecorded.

Rostrum considerably shorter than in *gangeticus*, with indications of marked upward curvature. Premaxilla expansion very slight with interdental pits, mesad of tooth row.

Gavialis pachyrhynchus Lydekker.
Level: Lower Siwalik (? Chinji), Upper Miocene.
Known from extremity of cranial rostral back to fourth maxillary tooth, also middle portion. With interdental pits in line with tooth row.

Premaxillary teeth *3-3* much larger than maxillary, latter also large and closely spaced, space about half the diameter of tooth. Space of three teeth a little more than half the width of the rostral.

Cranial characters unknown.

Premaxillary expansion very marked with the notch for first mandibular tooth roofed over by bone.

Size huge—Three times that of a 20 foot *gangeticus.*

Gavialis curvirostris var. *gajensis* Pilgrim.
Level: Gaj horizon of Bugti Hills, Lower Miocene.
Known from cranial rostrum from orbits forward. Mandibular symphysis, part of cranium.

Teeth 22 above; 15 included in the symphysis of mandible, rather widely spaced, three alveoli about three-fourths the width of the rostrum.

With interdental pits, mesad of tooth row.

Profile not abruptly depressed in front of orbit. Orbital rim not prominent. Orbits wider transversely than in *gangeticus*, interorbital bar narrower than in *curvirostris.*

Rostrum short, but excessively curved upwards; with terminal expansion.

Parietal bar about one-and-one-half times the width of the interorbital. (Judging from the photo which is obscure in region of S.T.F.)

Gavialis breviceps Pilgrim.
Level: Gaj horizon of Bugti Hills, Lower Miocene.
Known from cranial rostrum and mandibular symphysis.
With interdental pits, mesad of tooth row.

Teeth large but very near together, three alveoli equal half the width of rostrum. Alveoli almost in contact with one another.

Profile not abruptly depressed in front of the orbit. Anterior border of orbit not prominent.

Rostrum short compared with the width and very massive.

Premaxillae somewhat expanded.

Comparison of *Gavialis lewisi*, sp. nov.
With Other Species.

Gavialis lewisi.

Differs from *breviceps* Pilgrim—in time.

In the absence of interdental pits.

Teeth smaller and not so closely spaced.

More abrupt depression in front of orbit: apparently longer and more slender rostrum. Only the rear of the rostrum, however, can be compared.

Differs from *curvirostris* var. *gajensis* Pilgrim, also in time.

In the absence of interdental pits.

More abrupt depression in front of orbit.

More prominent orbital margin.

Orbits much more widely spaced.

(Query: Has Pilgrim reversed the ends of the cranium so that he is speaking of the S.T.F., rather than the orbits?) If so the spacing more nearly corresponds, but the S.T.F. of *lewisi* are not elongated transversely, as in *curvirostris* var. *gajensis*.

No indication of excessive curvature of rostrum, though not much of it can be compared.

Differs from *curvirostris* Lydekker in time.

Also in the absence of interdental pits.

Much more abrupt depression of profile.

Anterior margin of orbit much more prominent. Orbits farther apart, hence interorbital bar much wider. Posterior portion of rostrum deeper in proportion to breadth.

Remainder cannot be compared.

Comparison with *pachyrhynchus* Lydekker.

No direct comparison possible.

But *pachyrhynchus* is huge, ponderous, and has maxillary interdental pits, which are absent in *Gavialis lewisi*.

The teeth of the latter are more slender and widely spaced than in *pachyrhynchus*.

Comparison with *hysudricus* Lydekker.

Agree in absence of interdental pits.

Agree in profile and prominence of orbital rim and width of jugal and quadratojugal.

Differ in relative width of interorbital and parietal bars. In *lewisi*, the former, the ratio is as 4 to 1, in *hysudricus* as 2 to 1.

Supratemporal fenestrae relatively larger in *lewisi*, with the greater diameter fore and aft instead of transversely.
Other details not comparable.

Comparison with *leptodus* Falconer and Cautley.

Differ in absence of interdental pits in the new species which has proportionately larger teeth.

In *leptodus* the rostrum is relatively wide and flat, which may not be true of *lewisi*, but the exactly equivalent parts are not preserved; hence, cranium cannot be compared.

Comparison with *Gavialis browni* Mook.

Differs in the abruptly depressed profile in front of the orbits and the everted orbital rim in *lewisi*.

The teeth seem to agree in their relative size and spacing.

In *browni*, three alveoli equal about three-quarters the rostral width, in *lewisi*, less than half.

They differ in form of supratemporal fenestrae in that the antero-posterior diameter is the greater in *lewisi*, in *browni* the transverse. Interorbital bar of *lewisi* proportionately wider as compared with the parietal as 4 to 3.

Palatal vacuities in *lewisi* shorter, with inner margins divergent anteriorly, in *browni* they are long and the inner margins are parallel.

Posterior nares not preserved in *browni*.

The presence or absence of interdental pits in the maxillae for the reception of the mandibular teeth, has been considered by Lydekker of such prime importance that he divides the gavials into two groups on that character alone. Group *A*, those in which the pits are lacking, which would include *Gavialis gangeticus*, *hysudricus*, *browni*, and *lewisi*. Group *B*, on the other hand includes *Gavialis leptodus*, *curvirostris*, and the variety *gajensis*, *pachyrhynchus*, *breviceps*. On the strength of this character alone the affinities of our species lie with *gangeticus* and *hysudricus*, especially with the latter. The dorsal aspect of the cranium shows the principal points of the contrast, however, in the relative spacing of orbits and supratemporal fenestrae and in the form of the latter. The palatal aspects cannot be compared owing to the absence of either figures or description, other than the statement that *hysudricus* "apparently agrees very closely with *Gavialis gangeticus*" (Lyd. 1886, p. 15).

Gavialis hysudricus agrees with our species in being of Middle Siwalik age although whether of the same level is not recorded. Geographically the type specimen of *hysudricus* came from the neighborhood of the Satlej Valley.

EVOLUTIONARY TRENDS.

Crocodiles of the genus *Gavialis* have a long geological history, from the Lower Miocene, Gaj horizon, to the Recent, a duration of many millions of years. Certain evolutionary trends are of course apparent in so long lived a group, although the distinctive gavial features are present in the most remote forms thus far known, derived from some unrecorded ancestry. As is often the case the recorded changes deal largely with the skull and more particularly with the food-getting mechanism. What skeletal changes occurred are not recorded, for rarely if ever has associated material been found *with* the specimens which constitute the various types.

The principal items of change of which there is documentary evidence, lie in the gradual elongation of the rostrum, from the short muzzle found in *breviceps* to the long, narrow beak of the modern gavial. The terminal swelling of the rostrum, on the other hand, is a very ancient character, although not all of the species in which this portion of the rostrum is preserved, show it, notably *Gavialis curvirostris* in which the terminal expansion is very slight. The profile of the skull also varies tending toward a greater depression in advance of the orbits and a correlated abruptness of the anterior border of the orbit itself. The degree of curvature of the rostrum as a whole seems, however, to diminish somewhat with time for it is very marked in *Gavialis curvirostris*, especially the variety *gajensis* which is one of the two earliest known gavials. The dentition varies in the size and spacing of the teeth, but does not seem to be progressive, on the other hand the presence of interdental pits in the maxilla for the reception of the apices of the mandibular teeth is an ancient feature and tends to disappear with time, apparently bearing some relationship to the length of the mandibular teeth themselves. These pits while alternating with the maxillary teeth, lie within or mesad to, the line of the tooth alveoli in the earlier forms; are in line with and between the alveoli in those of intermediate age and are entirely lacking in the later species including the existing gavial. Their presence, however, in *Gavialis leptodus* is an apparent

exception, unless the assignment of that species to the Upper Siwalik is an error for the only other species showing a comparable condition is the Lower Siwalik *Gavialis pachyrhynchus*. If *leptodus* is actually Upper Siwalik it is persistently primitive in this detail.

CONCLUSION.

The Yale specimen seems to represent a new species of Gavials nearest *Gavialis hysudricus* which is an approximate contemporary of Dhok Pathan—Upper Middle Siwalik age. It represents a form which, except for its robustness, embodies the essentially modern characters of gavialoid evolution except that the relative length to breadth of rostrum and the dilatation of the snout, if any, are unrecorded in the type. In the abruptness of profile curve, the form of orbits, and absence of interdental pits in the maxilla it has reached the culmination of evolutionary trend. The peculiar character of the choanae with the pronounced anterior parapet is seemingly unique, for in Mook's description of *Gavialis gangeticus*, he says the internal narial aperture "is not protected from any direction, at the surface of the palate by an elevated plate of bone." (Mook, C. C., 1921, p. 182.)

ACKNOWLEDGEMENTS.

The writer is indebted to Prof. G. Edward Lewis for placing these interesting fossils, together with the accompanying field notes and other material in his hands for study and description, and to Dr. Edwin D. Colbert of the American Museum of Natural History for his constructive criticism of the result. Mr. Colbert feels that some of the points raised in connection with specific distinction, such as the presence or absence of interdental pits, and especially the relative dimensions of the interorbital width and the distance between the supratemporal fenestrae may be due to ontogenetic variation and hence be growth characters and not of specific value. As sufficient recent material is not now available for study, this criticism will have to stand as unproven for the present and the points of distinction offered for what they are worth.

It is quite evident that too many species of gavials have been erected on very inadequate material; but their history, though meagerly recorded, is a long one and specific differentiation seems to be within the possibilities of time and circumstance.

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"PAVEMENT-BOULDERS" AS INTERGLACIAL EVIDENCE.

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ABSTRACT. "Pavement-boulders," either singly or in groups, may indicate major or minor erosional interludes interrupting the progressive accumulation of subglacial till. The interpretation of faceted stones in general is involved and deserves careful consideration. Especially, striae of the pavement-boulder type should be distinguished from striae engraved on a stone during transportation. The common interpretation of true facets as originating largely during transportation is believed to be erroneous. Rarely, a single faceted boulder may afford basis for broad interpretation.

INTRODUCTION.

According to the younger Hugh Miller (1884), Hugh Miller, Sr., widely known for his book "The Old Red Sandstone," originated the term boulder-pavement in 1852 to denote a group of boulders imbedded in till and having glacially faceted and striated upper surfaces lying approximately in a common plane, the striae on the several surfaces being oriented in essentially the same direction. Each stone was called a pavement-boulder. The term boulder at that time apparently denoted a stone of any size, though a boulder-pavement evidently consisted chiefly of cobbles and boulders as now understood. The phenomenon had been known, however, since 1828 when Charles Maclaren ascribed the striae to the action of currents of water. The earliest description of an American locality, near Oxford, Ohio, (Stoddard, 1859) shows that such striae may indicate the direction of glacier movement as accurately as striae on bedrock. Of course the earlier observers had reached the same conclusion, though Stoddard's interpretation seems to have been made independently. In 1898 Gilbert described a well developed boulder-pavement separating tills of slightly different colors in western New York. He concluded that the section recorded a glacial readvance involving some erosion of the earlier till, but he states that the exposed zone of contact contained no evidence regarding the possible duration of the intervening time of recession.

Both Miller and Gilbert believed that boulder-pavements originated by selective erosion of previously deposited till, the finer fragments being removed while the coarser were pressed

down into the till matrix. The erosion may have been essentially contemporaneous, as when temporary renewed impetus "... caused the ice to attack its own deposits." (Miller, 1884, p. 173), or, as Gilbert suggests, the erosion may possibly have occurred after the lapse of an interglacial interval. Comparison of the relative concentration of boulders in the pavement and in the subjacent till may afford a general index as to the minimum thickness of till removed, which may exceed the average depth of significant weathering of the supposed earlier till sheet. In that event, however, at least part of the boulders may bear evidence of having been in the weathered zone and may constitute valid evidence of interglacial time.

RECOGNITION OF PAVEMENT-BOULDER STRIAE.

Boulder-pavement phenomena may be relatively obvious where the composing boulders are numerous even though the ice may have turned or rotated some of them during the striating process. With fewer boulders interpretation becomes less certain. Many tills contain so few stones of suitable size that true pavements are not likely to occur, although such stones do occur singly and may serve as a guide to further and more positive evidence concerning the conditions of deposition.

Glacially produced facets on stones should be carefully distinguished from flat surfaces originating in other ways and bearing striae in all respects comparable to those on adjacent rounded surfaces. Such striae, originating in transit, are proportionate to the size of the stone and record its frequent and relatively free turning in the ice-and-drift matrix. Plate 1. Fig. 1 illustrates the contrast beween transportational and pavement-boulder striae. The dark limestone cobble, about seven inches in maximum diameter, was collected at Chittenango Falls in Central New York. It was probably rounded by stream wear before it was acquired by the glacier. Fine striae in apparently random orientation were engraved over its surface, the lines conforming easily to the surface irregularities. By contrast, the pavement-boulder striae are coarse and definitely tangential to the rounded surface and are postdepositional. The stone, then firmly imbedded in compact till, formed a part of the floor over which the glacial load moved producing the set of striae shown from upper right to lower left in the photograph. Then a stone in transit impinged upon the cobble in

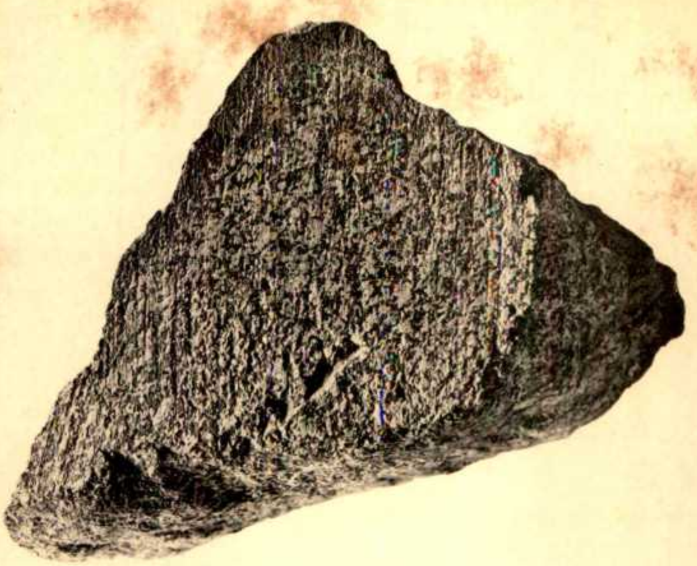

Fig. 2.

Fig. 1.

such a way as to cause slight rotation counterclockwise, and a second set of coarse, tangential striae followed. With further uncovering, the ice tended to divide and to flow around the stoss side, and the large scars from impinging stones testify to the firm grip of the inclosing till although ultimate dislodgement may have occurred. Had the glacial load which moved across the cobble contained only smaller stones and abundant sand, faceting probably would have developed rapidly.

At least one drift-filled interglacial gorge occurs at Chittenengo Falls (Holmes, 1935), but the stone shown in Plate 1, Fig. 1 is believed to represent only Wisconsin glaciation.

PAVEMENT-BOULDER AS INTERGLACIAL-HORIZON MARKER.

Plate 1, Fig. 2 shows a fragment (maximum dimension five inches) from a diorite boulder about two feet in diameter. The specimen was collected at Gillaspie School, four miles northeast of Columbia, Boone County, Missouri, and came into the writer's possession through the courtesy of Prof. Donald L. Blackstone, Jr. The exposure where the boulder was found is slumped, and although it was suspected to include the contact between the Nebraskan and Kansan drifts, the boulder fragment is the only ascertained evidence that both drifts are actually represented there. Nebraskan gumbotil was known a few miles to the northwest and was identified later at a nearby locality at approximately the same elevation. Thus the testimony of the fragment was substantiated, but the fragment itself merits consideration for the completeness of its testimony.

The striated surface shown by the photograph, Plate 1, Fig. 2, is a portion of a glacially cut facet that formed the top of the boulder, the ice having moved from left to right. Relatively unaltered rock comprises the center of the facet as shown, and is bordered on the left and on the near end by a kaolinized zone nearly an inch wide that marks the outer part of the boulder. The upper and lower margins represent two of the many intersecting fractures that divided the boulder into irregular pieces, though along most of the fractures complete separation had not occurred naturally at the time of collection. Oxidation of iron in the mafic minerals had extended through a quarter-inch zone on either side of the joints and is well developed on the fragment.

Interpretation of the beveled stone may be stated as follows: The nearest possible source of the diorite erratic is a few hundred miles to the north. Chemical alteration since the facet was cut has been practically nil, the surface of the unaltered part still retaining the high polish imparted to it by the Kansan glacier. The weathered, fragile condition of the boulder with its inch-thick kaolinized zone intact except at the facet definitely indicates that the weathering took place at the locality where it was discovered, and not at its place of origin. Therefore Nebraskan ice brought the boulder to the locality, where it became much weathered during Aftonian time. The degree of alteration corresponds to that observed on other similar stones slightly below the base of the gumbotil. The Kansan glacier evidently eroded the overlying drift and beveled the top of the weathered boulder. The upper left corner of the fragment as illustrated shows a second set of striae indicating some disturbance of the boulder, though actual removal of the boulder from its place in the Nebraskan till is unlikely. Kansan drift then shielded the stone from further alteration until the present.

GENERAL INTERPRETATION OF FACETS.

The expression "faceted and striated" has been used somewhat loosely in the literature describing glacial deposits. Original flat surfaces on stones from jointing, stratification, or fracture may persist even after considerable glacial wear and are not properly called facets, as the word facet in this connection implies shaping or cutting. However, glacially faceted stones are reasonably common. They are popularly supposed to have been frozen fast in the bottom of the glacier while the latter moved over a rock floor whose hardness was equal to (or greater than) that of the stone being faceted. This may be true of the relatively rigid carapace of a valley glacier, but at least two objections are offered to the general interpretation. First, recent studies (Demorest, 1938, 1942) indicate that the basal ice in glaciers is too plastic to hold a stone thus in a constant position through the necessary distance. Secondly, as in northern Missouri, the drift contains many sharply faceted granites and quartzites in areas where the bedrock is predominantly shale and weak sandstone which would not have produced the facets. Moreover, much of the floor must have consisted largely of till subglacially deposited.

The pavement-boulder concept seems to meet all the requirements of glacial faceting. Unfrozen, clayey till compacted beneath a glacier is believed adequate to hold a stone with sufficient firmness while the passing ice, laden with sandy drift and stones of moderate size, constitutes an ideal abrasive mechanism. The faceted stone may or may not remain permanently imbedded at that place. Hugh Miller (1884, p. 182) evidently had this process in mind when he wrote: "I have frequently seen little bits of shale, not more than 1/10th of an inch deep, of which the upper surface was well rubbed, while the lower surface was almost untouched. *The sole of the boulder*, as Robert Chambers used to term their flatter side, seems generally, in fact, to have travelled uppermost."

CONCLUSION.

Stones having a true facet of appreciable dimensions record a time of glacial erosion which may be equivalent to a major unconformity or to an insignificant hiatus. Rarely a single faceted stone may indicate the former, while a well developed boulder-pavement may afford evidence only of the latter. Numbers are not necessarily significant. A shift in glacier activity from deposition to erosion may well indicate renewed movement following temporary stagnation and may thus relate to minor substages of glaciation. Though the time value of the erosion surface as seen in section may not be readily apparent, the occurrence may be suggestive of further evidence to be sought.

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TWO NEW PLANKTONIC CRUSTACEANS FROM THE MAQUOKETA SHALE (ORDOVICIAN OF ILLINOIS).

JOHN W. WELLS.

ABSTRACT. Descriptions of two new genera and species of peculiar crustaceans from the Maquoketa shale (Upper Ordovician) of Illinois: *Paramarria galenensis*, allied to the Middle Cambrian *Marria walcotti* Ruedemann; and *Galenocaris campbelli*, a ceratiocarian phyllocarid.

INTRODUCTION.

THE greatest number of fossils of marine organisms are those of benthonic forms possessed of more or less rugged endo- or exoskeletons. Next in abundance are the remains of nektonic animals. Planktonic species, excessively abundant today and unquestionably equally so in the past, are by comparison very scarce as fossils, seemingly because of their unsuitability for preservation. Hence our outlook on ancient life or ancient life communities, in one plane strongly skeletomorphic, tends in the other to be benthono- and nektomorphic. This astigmatic condition is generally recognized by paleontologists, and any chance recovery of material which helps ever so little to correct it in either plane is of interest.

The two new crustaceans described below are believed to have been holoplanktonic, one of them, a marriocarid, seemingly passive (kremastoplanktonic), the other, a phyllocarid, a weak swimmer (neidioplanktonic). Both were found in a small collection from the graptolite zone (Trowbridge and Shaw, *1916*, p. 70; Ladd, *1929*, p. 386) in the lower part of the Maquoketa shale in the vicinity of Galena, Illinois, made by M. R. Campbell in 1888, which has reposed since then practically untouched in the collections of the Ohio State University Geological Museum. This phase of the Maquoketa contains a mixed graptolite assemblage of a few benthonic and some planktonic forms: *Climacograptus typicalis*, *Diplograptus foliaceus*, *Cleidophorus neglectus*, *Isotelus maximus*, a small gastropod, several large and small orthoceraconic cephalopods, and the two new crustaceans.

The preservation of all the fossils except the graptolites is poor, and the crustaceans appear as impressions in the gray-

green, clayey shale. The impressions are lined with a finely granular or powdery black film of pyrite and carbonaceous material. The edges of the appendages and body of the marriocarid, as seen under the microscope, are not sharp; the carapace margins of the phyllocarid, however, are sharply defined. The chitin of the graptolites occurring in the same matrix is well-preserved and shiny, with sharply defined edges. This contrast between the poorly preserved lustreless tests of the crustaceans and the well preserved glistening stipes of the graptolites has been pointed out in the case of similar associations by Størmer (*1937*, p. 270) from the Ordovician of Norway, and by Ruedemann (*1934*, p. 94) from the same system in New York.

The writer is grateful to Dr. Rudolf Ruedemann for examining photographs of the specimens and who agrees with the conclusions expressed below concerning their systematic position.

DESCRIPTIONS.

Order ENTOMOSTRACA.
Suborder MARRIOCARIDA Ruedemann.
Family MARRIOCARIDAE Ruedemann.

Paramarria galenensis, n. gen., n. sp.

Plate 1, figs. 1, 2.

Description.—Body small, measuring in compressed condition, 1.3 mm. in length, 0.7 in width, seemingly elliptical in outline with truncated anterior end. Subdivisions of body or segments indiscernible. Between the forward projecting bases of the first pair of antennae is a faint, confused mass possibly representing remnants of the body, which may have been considerably longer.

Appendages consisting of three pairs of grotesquely developed swimming organs fixed to the anterior corners of the body. The first, anteriorly directed pair is represented only by protopoditic stumps, and is, compared with the others, apparently uniramous. The second pair is biramous, with stout protopodites directed anteriorly and from which the exopodites extend slightly forwards, the endopodites laterally. The third is like the second but the exopodites are directed slightly backwards and the endopodites nearly backwards. Each of the exo-

and endopodites in turn bears 7 or 8 (possibly more) pairs of long exites and endites, about 1 mm. in length and spaced about 0.25 mm. apart, forming two rows extending laterally from the limbs in the body plane. None of these appendages is preserved in its entirety and it is likely that a quarter or a third of their distal ends is lacking. The jointing of the appendages is scarcely discernible but at each joint there seems to have been attached an exite and endite pair. There are obscure traces of setae on the posterior edges of the secondary branches. Extreme width of the specimen, 10 mm.

Occurrence.—Lower Maquoketa shale, Upper Ordovician, in the vicinity of Galena, Illinois.

Holotype.—No. 7456, Ohio State University Museum.

Remarks.—The three pairs of appendages are strikingly like those of crustacean larval forms such as nauplius, and if homologous, they represent the first (uniramous) and second (biramous) antennae and mandibular (biramous) pairs of that type. Compared to those of nauplii, they are even more extended and suggest an almost wholly passive, pelagic, habit. The test must have been exceedingly thin and transparent, scarcely fit for fossilization.

The resemblance of this curious form to *Marria walcotti* Ruedemann (*1931*, p. 4, pl. 4, figs. 2, 3; pl. 5) from the Middle Cambrian Burgess shale, is unmistakable and there can be little doubt that the two pertain to the same crustacean group. Ruedemann concluded that *Marria* represented a new entomostracan suborder, the Marriocarida, linked only to other crustaceans by its resemblance to the nauplius and protozooea of the less primitive suborders,—a similarity perhaps significant phylogenetically. *Paramarria*, from its resemblance to *Marria*, is accordingly placed in the Marriocaridae, and on the basis of our present faulty knowledge of both forms, differs from the family type in its appendages. In *Marria* there are only two pairs of biramous swimming organs—the second antennae and mandibulae—on which secondary branches are largely developed from only one side except proximally where both endites and exites appear; in *Paramarria* there are three pairs of such organs, the first, conjecturally uniramous, being the first antennae, the other two, biramous, the second antennae and mandibles, all with complete rows of exites and endites on each member. No appendages can be made out on the posterior part of the body of *Paramarria*; the presence of several pairs of

exopodites in this region of *Marria* is indicated by Ruedemann. The exites and endites of *Paramarria* seem to have been less tenuous and stiffer than in *Marria*, hence their more formal aspect in the conjectural partial restoration (Pl. 1, fig. 2).

Order PHYLLOCARIDA.

Suborder CERATIOCARINA Clarke.

Family CERATIOCARIDAE Salter.

Galenocaris campbelli n. gen., n. sp.

Plate 1, figs. 3, 4.

Description.—Based upon the two connected valves of a single carapace, preserved as an impression of the external surface. Valves in contact along the dorsal line at a very obtuse angle. Hinge line seemingly a simple symphysis shorter than the rest of the valves, marked by what may be either a dorsal ridge pertaining to both valves or a dorsal median lance plate overlapping or lying between both valves. No lateral ridges or carinae, the exterior of valves being ornamented only with faint wrinkles concentric with the margins except along the narrow borders, which are smooth. No trace of cephalic nodes or "eye spots." Valves straight above, elliptical below, curving up less quickly before than behind, where there is a fuller curve meeting the truncate posterior edge, which slopes downward at about 65° at the mid line of the valve. Juncture of posterior and ventral edges produced backwards as a blunt subspiniform process. Anterior edge sloping a little less steeply than the posterior, meeting the abruptly upturned ventral margin to form an obtuse anterior point dorsad of the mid line of the valve. Dorsal ridge prolonged forward beyond the anterior margin but not as far as the most anterior part of the valve. This median projecting process might be interpreted as the rostrum, not commonly found in place, or simply as the prolongation of the anterior dorsal angles of the valves, as in *Silesicaris nasuta* (Gürich, *1929*, p. 27, figs. 2, 5, 6), but much less developed than in that species.

Dimensions.—Greatest length of valves, 21.5 mm.; length of dorsal hinge, including "rostrum," 18 mm.; greatest width across both valves, 17.5 mm.

Occurrence.—Lower Maquoketa shale, Upper Ordovician, in the vicinity of Galena, Illinois.

Holotype.—No. 7458, Ohio State University Geological Museum.

Remarks.—The condition of the single specimen of *Galenocaris* makes it difficult to decide the nature of the union between the valves, a significant feature of subordinal value. The principal distinction between the two suborders, Ceratiocarina and Rhinocarina, in one of which the new form obviously belongs, lies here. In the more primitive group, the ceratiocarians, the valves seem to have been united by a thin membranous symphysis, easily ruptured with resulting separation of the valves; in the rhinocarians, first appearing in the Devonian, the valves were in contact only at a single point near the anterior end where they actually overlapped—behind this they were separated by an elongate lanceolate median plate which either overlapped the valves or fitted between them, and in front of this juncture the rostral plate lay between the valves and projected beyond the hinge axis. The hinge in *Galenocaris* is marked by a fairly high, well-defined ridge between the valves that is strongly suggestive of the rhinocarian median plate. In practically all rhinocarians there is a spinelike projection from the posterior border of each valve; in ceratiocarians such a projection is not developed and the posterior margin is either rounded or subacute, although in some forms such as *Eleutherocaris whitfieldi* (Hall and Clarke, *1888*, pl. 29, figs. 20, 21) of the New York Upper Devonian, there is a weak posterior projection. In *Galenocaris* the blunt posterior spine is conspicuous. Cephalic nodes and lateral carinae are present in all rhinocarians; they may or may not be present in ceratiocarians; neither is found in *Galenocaris*. Thus, *Galenocaris*, on the basis of its hinge line, may prove to be either a rhinocarian or ceratiocarian; on the basis of the posterior spine, a rhinocarian; and on the basis of the absence of cephalic nodes and lateral carinae, a ceratiocarian of the family *Ceratiocaridae*. Pending better data on the nature of the hinge line, it would seem that of the other two

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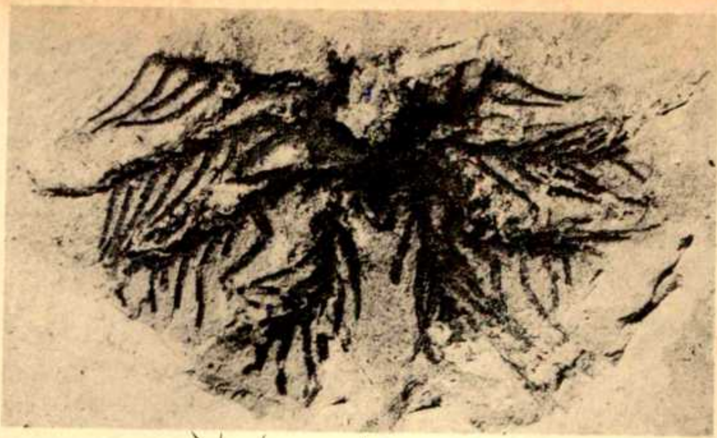
EXPLANATION OF PLATE I.

Figs. 1, 2. *Paramarria galenensis*, n. gen., n. sp.
Maquoketa shale, U. Ordovician, near Galena, Ill.: 1, holotype X9 (OSU 7456); 2, partial reconstruction, X9.

Figs. 3, 4. *Galenocaris campbelli*, n. gen., n. sp.
Maquoketa shale, U. Ordovician, near Galena, Ill.: 3, holotype carapace, X1.6 (OSU 7458); 4, diagrammatic sketch of carapace, X1.8.

(Photographs unretouched.)



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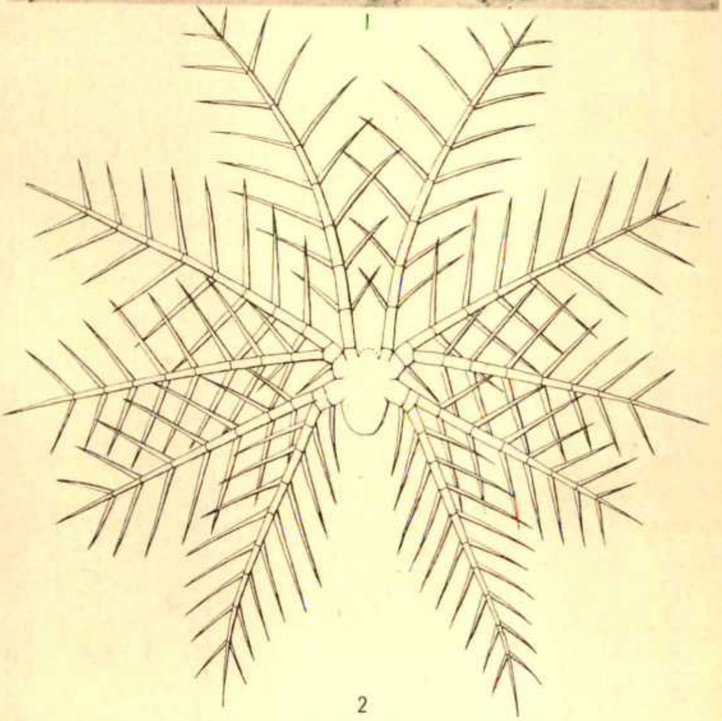

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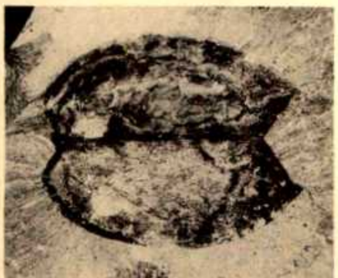

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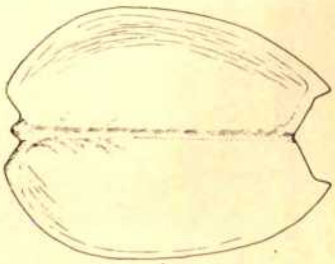

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structural elements, the development of the posterior spine is less significant, and *Galenocaris* is provisionally assigned to the Ceratiocaridae. From the other genera of this family it is distinguished by the posterior spine.

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and rates of flow, the relationship became $V = kH^{1/N}$, when N becomes less than 1, giving the exponent of H values that are progressively more than 1. Thus the rates of flow with declining heads were reduced more rapidly than the first power of the head, an apparent deviation from laminar flow exactly opposite in character from turbulent flow, where in the customary notation, N is greater than 1.

The same deviation from expected rates at small velocities in thin cracks is shown by reference to the thickness of the crack, following an analogue to the Hagen-Poiseuille law. This law states that under constant head the flow of a liquid through a capillary tube is proportional in velocity and in volume to the fourth power of the radius of the tube. The law is deduced from the elementary assumptions of pure laminar flow by equating the force inducing flow to the viscous resistance which opposes it, the derivation being given in various textbooks on fluid mechanics.[1] By an analogous derivation, with appropriate differenees in the dimensions, it can be shown that the rate of viscous flow in a crack, at constant head, is proportional to the third power of the width of the crack. Both these laws follow strictly from Darcy's law and are only forms of statement in relation to size and shape of opening.

In the forms of apparatus which the writer first used, it was more convenient to work from high to low heads, with tests often running over a period of several hours. After a number of runs had been made and in connection with a change in apparatus, it was learned that the reduction in rate of flow with lowered heads was also in part a function of time and that the appearance of what had been called "sub-laminar" flow, where N is less than 1, was actually due to some change which took place with passage of time, even at the same head. It, therefore, was incidental to the progress of measurements from high heads to low heads.

When this state of affairs was probed with suitably arranged apparatus, it was found that in thin cracks of less than 0.1 mm. the flow of water under a constant head in course of 10 to 100 hours becomes systematically reduced to values as low as 1/100 or 1/1000 of the initial rate. Determination of this fact, including experiments with liquids other than water, and an attempt at explanation of this behavior is the occasion for this paper.

[1] Dodge, Russell A., and Thompson, Milton J.: 1937, Fluid Mechanics, pp. 171-174, McGraw-Hill, New York.

ORIGIN OF LOESS—A CRITICISM.

CHAUNCEY D. HOLMES.

INTRODUCTION.

A RECENT paper by Russell[1] has brought the loess question again into serious consideration. The paper is addressed to all who have occasion to deal with the deposits called loess, and to the many who, the author fears, have pictured the Mississippi Valley loess as "a gigantic dunelike ridge extending from the Ohio River to Louisiana, with a high scarp facing the Mississippi and a gentle eastward slope leading to a feather edge some 10 to 15 miles away."[2] Readers of the paper will profit by the somewhat historical treatment of the subject and will find the extensive bibliography useful.

According to the author, the loess question has been particularly troublesome chiefly for two reasons: application of the term to too wide a variety of deposits, and insistence on eolian origin. General agreement on the former proposition can be anticipated, but probably not on the latter. The author champions a new process hitherto neglected or unknown, which he calls loessification. Given appropriate source material, soil creep and its associated processes, acting through a downslope distance of 0.2 to 0.3 of a mile, is said to effect the high degree of size-sorting characteristic of loess. Loessification is essentially complete when subsurface water has introduced sufficient calcium carbonate to serve as a weak cement which halts further creep (or colluviation). Subsequent loss of essential characteristics by weathering is called deloessification. The partially loessified product and other silts resembling loess are classified as loesslike materials.

Russell defines loess as "unstratified, homogeneous, porous, calcareous silt; it is characteristic that it is yellowish to buff, tends to split along vertical joints, maintains steep faces, and ordinarily contains snail shells. . . At least 50%, by weight, must fall within the grain size fraction 0.01-0.05 mm., and it must effervesce freely with dilute hydrochloric acid."[3] In the

[1] Russell, R. J.: 1944, Lower Mississippi Valley Loess: Geol. Soc. America Bull., Vol. 55, pp. 1-40.

[2] Op. cit., p. 34.

[3] Op. cit., pp. 4-5.

Definitions.

In the discussion which follows we are primarily concerned with rate of flow of a liquid. This rate, often referred to as flow, is measured in most instances as a volume rate, in cubic centimeters per second.[2] In some experiments this has been translated into mean velocity in centimeters per second, but in most it has not, since we are interested chiefly in changes in rate with passage of time. Constants of each of the experiments include the head, measured in centimeters, thickness of crack, measured normal to the plane of the walls, width of crack, measured normal to the thickness and to the direction of flow, and the length, paralleled to the direction of flow. Contained in the k of a full equation is the density of the liquid as well as its viscosity. Since none of the experiments are intended as absolute measurements under reproducible conditions, most of the dimensions are omitted from the data presented. The precision of measurement varies according to instruments used. Rates are mostly of a relative accuracy of about 1/50 at higher values and decline to 1/10 at lower values, which are sufficient in view of the large relative changes chiefly involved here.

Experimental Work.

Forms of Apparatus.

In the early experiments a frame was used in which the two halves of a split block of rock were mounted so that they could be separated to any desired amount by a screw adjustment. A simpler, fixed scheme was the mounting of the two halves in neat cement inside a cylindrical can which was then clamped with gaskets between plates carrying both flow and head gage tubes.

In some experiments the volume measurements were made in a graduated receiver. At lower flow rates, measurements were made in a small tube, in some instances of capillary size. In one arrangement, volume was determined by measuring rise or fall of the liquid surface through use of the fine adjustment of a microscope as a cathetometer. Here a contact point carried at one side of the microscope could be brought down to a spotlighted liquid surface with reproducible precision of less than 0.005 mm. Such measurements became impracticable only when the rate of change approached the current rate of evaporation from a free surface of about 0.1 mm. per hour.

[2] The unit milliliter, of precise value to chemists, is of no special significance here.

lower Mississippi Valley, this material is interpreted as having been derived by loessification chiefly from the backswamp clays of the higher Pleistocene terraces where these have been slightly dissected. Loess mantles the erosional slopes but "commonly fails to reach the summits of the slopes above them."[4] The function and importance of soil creep and allied processes in loess formation deserve more careful consideration than they have received in the past. However, the process of loessification as described will not convince the critical reader because some of the stated effects are definitely at variance with the processes as generally understood. More complete data may eliminate some of the objections, though others now appear more serious.

PROBLEMS OF LOESS DERIVATION.

Russell describes the parent material, backswamp deposits, as typically calcareous clay 50 feet or more in depth. "Silt and coarser sediments are restricted mainly to natural levees. . . Sedimentary complexity along the meander belts contrasts with simplicity in the backswamps . . . . [whose deposits] . . . are formed from the finest mechanical sediments."[5] He mentions later that "in typical backswamp deposits there is less sorting, and, on the whole, much finer material."[6] Russell does not report any grade-size analyses of the backswamp deposits, and the reader wonders how much silt, of which 50 per cent by weight falls within the grade-size fraction 0.01-0.05 mm., can be derived from a given quantity of backswamp clay. Apparently the ratio of parent clay to derived silt is high. As the clay must come from levels above the erosional slopes which the loess now mantles, from what parts of the terraces did the clay come? Removal of the requisite amount of clay by soil creep should have involved considerable topographic alteration, though Russell does not mention any such effects nor comment on their absence.

PROBLEMS OF SORTING.

Russell states that "the loss of finer particles goes on at all stages of colluviation and is intensified by churning movements. Surface washing probably contributes to some degree."[7] Also,

[4] Op. cit., p. 9.
[5] Op. cit., p. 18.
[6] Op. cit., p. 26.
[7] Op. cit., p. 24.

In experiments involving rates as high as 5 or 10 cc. per minute a constant head device with overflow control was used; with many runs at rates below 1 cc. per minute and with a supply jar of over 200 square centimeters in section the head was maintained sufficiently closely by successive additions of small amounts of water. In some runs the head was held constant and flow measured at the outflow end; in others the volumes were read in the head tube itself, with small head changes during each rate measurement. In general, heads have been held within 5 per cent of the stated value, with the mean much closer, standards which seem adequate for the study of the large relative changes in question.

Few of the many combinations of apparatus used justify detailed description. One device which was very useful was a multiple-tube, rate gage. This was required to allow making rate measurements over ranges in excess of 100 to 1 in short, comparable periods without drastic change of conditions. It consists of two or more tubes of large difference in cross-section with connection to the supply end of the system. For measurements at higher rates the larger tube is left in series, giving relatively smaller head changes; at lower rates the larger tube is cut off by pinchcock to provide relatively larger head changes and avoiding onerously long intervals that might otherwise be required for measurable changes. This device is also useful in maintaining nearly constant head (leaving the large tube connected) for a long period, but also at any time permitting valid measurements of slow volume changes (by cutting out the large tube and noting head change in the smaller). An ideal scheme is a battery of tubes in the area ratios

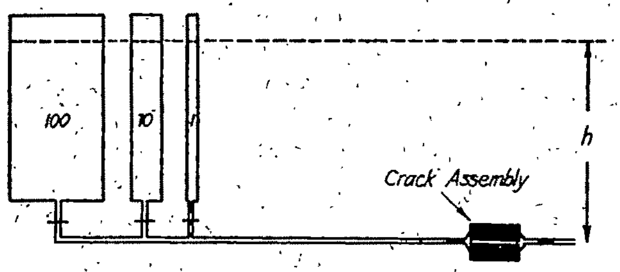

Fig. 1. Conventional diagram of multiple supply and rate-measuring tubes. Figures show the relative areas of free surface in cylindrical tubes. By use of pinchcocks, the larger tubes can be cut off progressively to give more rapid apparent rates for measurement and restored to the system to give more stable head maintenance.

"vertical translocation of smaller solids is essentially equivalent to that taking place in the differentiation of the A-horizon of a soil. Surface losses of finer material occur for various reasons."[8]

Loessification is not now in progress in the lower Mississippi Valley, but the author cites no evidence other than his assertion that "churning movements" were extensive or were effective in size-sorting. The reader may easily visualize churning as tending to mix the several grade-sizes rather than to segregate them. With increasing perviousness as loessification proceeds, removal of clay by surface washing would seem to entail at least some gullying with consequent loss of much silt. The "various reasons" might include wind action, but the attempt is to avoid appeal to eolian processes.

Presumably the major part of "vertical translocation of smaller solids" was downward, and they must have been left behind at the bottom during the sorting process. As mentioned above, the relative quantity of these smaller sizes must have been large. Somewhere on the slopes, beneath the partially loessified material, this vast amount of clay should be segregated. The author reports no attempt to locate such an accumulation. Gravel underlies some of the loess and a few stones occur in the basal portion of the latter. However, any churning movements involved in loess formation apparently did not destroy the well-defined basal contact. Downward migration and loss of the smaller sizes should make those sizes progressively more abundant downward in the transitional phases and even in the completed product, inasmuch as "residual concentration of coarser materials . . . continues until . . . mass movement is checked by cementation."[9] The author does not adequately consider this possible field relationship.

PROBLEMS OF MINERALOGY.

Discussion of the minerals involved in loessification is somewhat vague. Russell sees the beginning of loessification in "weathering and pedogenic processes . . . [which convert the upper part of the terrace material into] . . . brown loam that . . . creeps freely on slopes."[10] But he offers no explanation for the statement that "parent materials, well advanced in

[8] Op. cit., p. 30.
[9] Op. cit., p. 38.
[10] Op. cit., p. 38.

1:10:100, etc. (Fig. 1.) This general principle was used in several forms.

Several forms of small multiple metal cocks were constructed but in most instances it was found that pinchcocks on rubber tube connections were simpler and more positive in action. In several arrangements it was convenient to have interconnected by rubber tube into a manifold, containers having lower and higher heads than the outlet opening, so that the water column

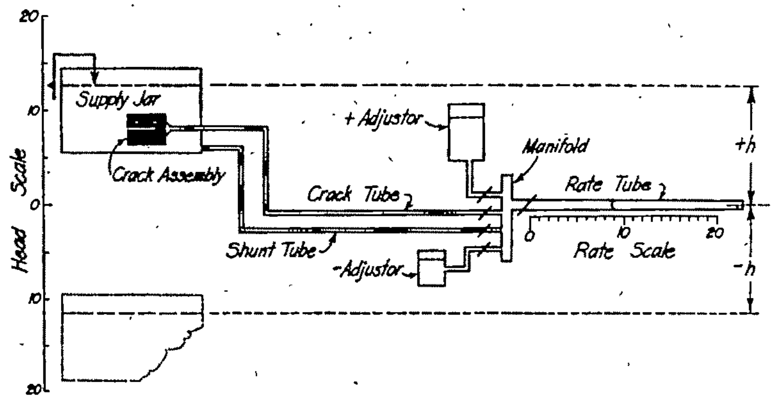

Fig. 2. Diagram of apparatus used for many runs at the lower flow rates. The supply jar was carried on a vertical slide post, with measuring point to refer to a metric head scale. The rate tube and manifold are mounted on a small board fixed to the table. Most of the other connections are rubber tubes and the supply jar has a total head range of nearly 200 centimeters. For long runs water can discharge from the rate tube, or can be drawn into this tube for flow in the opposite direction. Rate measurements in either direction are made by timing the air-water junction in this tube against the length scale.

used for measuring could be gently retracted or advanced at will for repeated measurements through the same range. These were controlled by pinchcock. (Fig. 2.)

Most essential part of the apparatus is the crack or orifice through which the flows take place. Much used was a pair of cylinders, one with a hole through its axis and the other without, clamped as shown in Fig. 3. The thickness of the crack was fixed by inserting three shims of metal or paper, which could be measured by micrometer. This form was most convenient for resetting the apparatus for a new run and cylinders of basalt, brass and glass were used.

Capillary tubes were also used as orifices, and capillary tubes with long, tapering glass filaments inserted to form a slow adjustment needle valve. Another plan for a restorable crack

loessification, differ mainly with regard to carbonate enrichment, not with regard to constituent particles."[11] After having undergone weathering and pedogenic processes, the "individual minerals ordinarily appear fresh and angular, . . . [and consist] . . . mainly of primary mineral and rock particles. . . Quartz grains are predominant. Calcite grains are conspicuous. Minor amounts of rock fragments, various heavy minerals, and other minerals characteristic of floodplain deposits are present in varying proportions."[12] These statements imply a fairly extensive mineral suite in which loessification should have produced significant changes. In the absence of explanation, the reader must wonder whether "weathering and pedogenic processes" really have no effect on rock fragments and minerals characteristic of floodplain deposits of the lower Mississippi.

The occurrence of calcite grains and their relation to carbonate enrichment raise questions not answered in the paper. Calcite seems to be listed among the detrital minerals supposedly segregated from the parent material which, however, is said to be noncalcareous and to have undergone weathering. As their origin under these conditions seems impossible, perhaps they were developed as a consequence of carbonate enrichment. If so, what is the process by which discrete calcite grains develop in a porous matrix? If they are concretionary forms, at what stage of enrichment do they appear? What is the grade-size distribution of calcite in the deposit?

Russell states that the carbonate content of loess has been found to range from approximately 4 per cent to 36 per cent. As this carbonate is supposed to be introduced after sorting and terminates the sorting process, a deposit in which 50 per cent, by weight, would be included within the prescribed grade-size limits with 4 per cent of added carbonate might fail to meet the grade-size requirement when the added carbonate amounts to 36 per cent.

PROOFS OF ORIGIN.

Russell cites chiefly two facts as proof that the loess was derived by colluvial processes. One is the apparent gradation into the terrace formations, and the other is the mechanical analyses which "commonly show a tail of fine grain sizes far

[11] Op. cit., p. 29.
[12] Op. cit., p. 30.

in any material is that of a lapped, long-taper joint like a stopcock, with a slight flat ground on one side. This is, however, less susceptible of accurate definition as to dimension of crack than the plane-parallel forms.

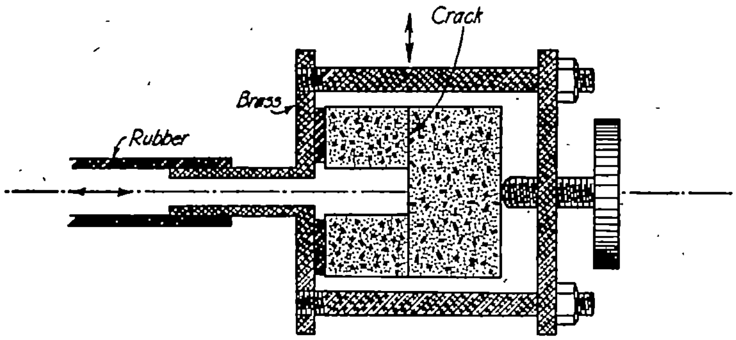

Fig. 8. Diagram showing crack assembly most used. This is a brass end clamp with rubber tube connection at one end. The two cylinders, one with axial hole, are clamped against the rubber gasket, and are held apart by three shims at 120 degrees to form a crack of the desired thickness. The tie rods, here shown diametrically opposite, are in reality at 120 degree spacing. The cut is about natural size.

Results of Measurements.

In this section certain of the experiments are presented in some detail; others are merely summarized or used as the basis for general conclusions. In all, approximately 100 runs were made, with various forms of apparatus, and involving from as few as 10 to 50 or more rate determinations each. A number of the earlier runs were made before the time effect was recognized. Typical examples of these are shown in Fig. 4. In this graph, lines A to D represent flow under conditions which show progressively less turbulent flow. Line C suggests nearly pure laminar flow with little or no retardation due to the effect described here. Lines E, F, G, and H show laminar and turbulent flow in plane parallel cracks. Laminar flow seems to persist over a longer range between smooth glass walls than between lapped basalt walls. Run No. 25, shown in lines G and I shows a long transition from pure laminar flow to retarded flow in which N falls as low as 0.1 at the lower end. Attempts to duplicate this behavior with modified arrangements of apparatus led to discovery of the time effect.

Retardation of flow with time alone and with head constant is shown in various of the runs numbered above 100, as set forth

beyond the coarse silts that constitute an overwhelming proportion of each sample."[13] From the photographs accompanying the paper, the "loesslike" intermediate material appears to grade into the leached loess overlying the calcareous loess, and apparent continuity into the "brown loam" on the terrace may mean only simultaneous development of soil on the loess and on the uppermost materials on the terrace. No evidence indicates that secondary-carbonate enrichment ever extended throughout the deposit now classed as leached loess, and the thickness of the latter seems to be comparable to that of the noncalcareous intermediate material. Analyses of these two phases show considerable similarity, and the possibility that both may have originated by postglacial weathering of a common source material seems a worthy hypothesis. At least their relationship should be clarified.

Occurrence of a "tail of fine grain sizes" seems to prove merely that some finer grade-sizes accumulated along with the coarser, and not that they represent necessarily a lingering residuum after such sorting as churning and colluviation can produce. Their occurrence also emphasizes the questionable propriety of defining the deposit as homogeneous.

No field or laboratory fact cited seems to disprove eolian origin for the loess in the lower Mississippi Valley. On the contrary, all the features seem compatible with the concept of wind transportation, with marked lodgment of the sediment in the dissected areas along the margins of the windswept terraces. The finer grade-sizes could have adhered to the coarser during transportation, or they may have lodged among the coarser as sand becomes entrapped among pebbles. Contemporaneous soil creep is probable. Detrital carbonate grains could be the chief source of secondary carbonate. It still seems "improbable that a material with such striking physical and field relationships has more than one origin."[14]

The loess problem appears to be as much involved with indistinguishable "fact, opinion, and hypothesis"[15] as before. Loessification must remain an hypothesis unless it can be supported by evidence more convincing.

[13] Op. cit., p. 26.
[14] Op. cit., p. 84.
[15] Op. cit., p. 83.

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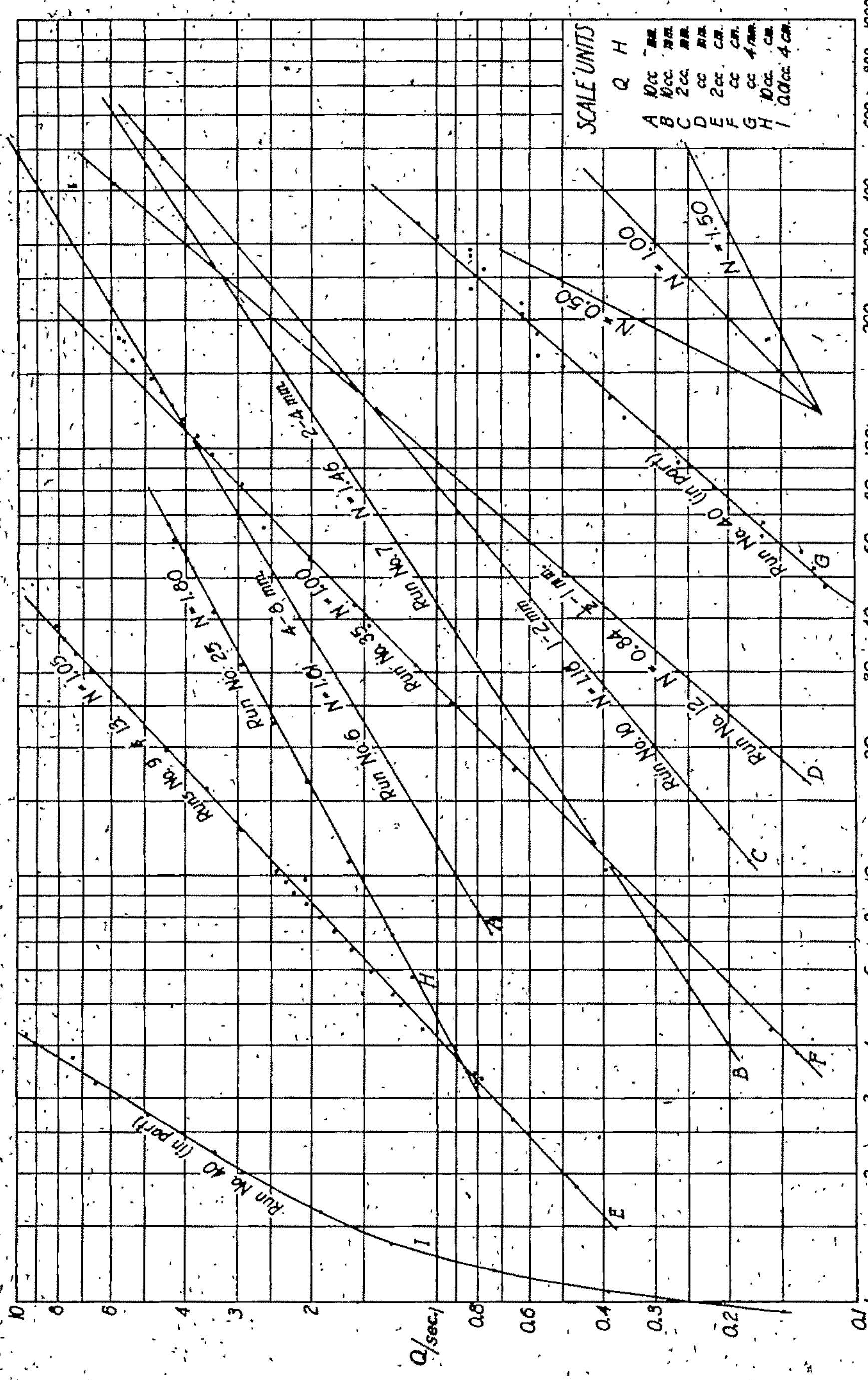
SCALE UNITS
Q H
H
Q/sec.
Run No. 40 (in part)
Runs No. 9 & 13.
N=1.05
Run No. 25
N=1.80
4-8 mm.
Run No. 6
N=1.01
Run No. 35
N=1.00
2-4 mm.
N=1.46
Run No. 7
1-2 mm.
½-1 mm.
Run No. 10
N=1.16
N=0.84
Run No. 12
N=0.50
N=1.00
N=1.50

Fig. 4.

DISCUSSION

ORIGIN OF LOESS—REPLY

Doctor Holmes' criticism appears to be based on internal evidence from my paper on lower Mississippi Valley loess rather than on actual familiarity with the deposits. It attributes to me several observations and opinions not stated in the paper and which I do not hold.

An impression is given that loess is associated with "slightly dissected" Pleistocene terraces, quite in contrast to my statements that "Other things being equal, a deeply dissected territory favors development" (p. 16), "In deeply dissected territory it creeps into valleys, where it accumulates to considerable thickness" (p. 24), or "Pleistocene terraces and underlying Tertiary formations have been deeply dissected in much of this [south of Natchez] territory, and loess mantles lead down slopes, with increasing thickness, to the deepest valleys. Extreme range in elevation, disregard for compass orientation, and movement across truncated strata are especially well exhibited south of Homochitto River" (p. 16). "When the Recent deposition started, the bluffs at Natchez were over 450 feet high, and subsurface borings show that the face now covered by alluvium was about as steep as the part exposed today . . . Each [loessification stage] may have been a glacial stage, when valleys were more deeply dissected and colluvial slopes were longer [than they are today]." p. 32.

It is possible that the last quotation given led Doctor Holmes to the idea that "Loessification is not now in progress in the lower Mississippi Valley." My own view is that "Loessification may be in progress today . . . but completion of the process may acquire an interval that has affected only [late Pleistocenee] pre-Prairie parent materials as yet" (p. 32). The right kind of parent material, long slopes, and sufficient time appear to be the necessary factors for loess formation.

In contrast to "any churning movements in loess formation apparently did not destroy the well-defined basal contact" are my statements, "In the lower parts of exposed limbs [of pseudoanticlinal exposures] there is a notable amount of gravel admixed in the loess, the thickness of the mixed material increasing downslope . . . Gravels in the admixed loess are gray; stones have random orientation and exhibit no evidence of stratigraphic continuity" (p. 11) . . . "there is no reason why a tooth or bone should not find its way into this material, just as gravel does" (p. 22), "Gravels are genetically foreign to loess but become incorporated during mass move-

below. Run No. 126 combines change of head with time effects. This consisted of flow through a 0.1 mm. crack in the plane, annular form with lapped basalt walls. The run commenced at plus 30 cm. head and continued at various lesser heads through zero to minus 30 cm. head, thence returning again through zero to plus 30 cm. Rate determinations were made at 26 head positions, and rate values were roughly in linear relationship to head but with some deviation. At each head-value three or more rates measurements were made, which showed at the larger positive heads a strong tendency toward retardation and considerable accumulated constriction as the smaller heads were reached. Zero flow was reached and flow reversed in direction at a head of plus 1.3 cm.

Through the increasing negative heads there was a slight tendency for the rate of flow at each head to increase with time, suggesting a possible clearing out of molecular film already formed in response to increasing velocities at higher heads. On returning, the flow showed a slowing with time at each head and zero flow was reached at minus 0.6 cm. of head. The flow rate returned at plus 30 cm. to about half the initial rate at that head, indicating a moderate cumulated retardation thought to be due to film formation. After applying pressure pulsations by rapid squeezing of the rubber tube the flow was measured as about 2 per cent greater than the first rate. Subsequently, with head remaining at 30 cm., the flow in 45 minutes decreased to 1/6 of the initial rate. The total time of the run was 217 minutes.

This run, in addition to showing the retardation with time, also showed that the process of film growth through a series

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Fig. 4. Representative graphs of rate against head for flow through several types of opening. Lines A to C show flow through a cylinder containing angular, crushed basalt of the grades indicated. Line D is for the next smaller grade but the specimen was coral sand. The coarser grades with N greater than 1.00 evidently permit some turbulent flow at the higher heads. Line D suggests the commencement of flow retardation. Lines E, F, and G show nearly pure laminar flow. E and F are for plane parallel cracks between glass plates, with 0.21 and 0.046 mm. separation, respectively. G is the nearly laminar portion of a long run in a 0.075 mm. crack between lapped basalt walls. H shows the course of a run in a crack 2.35 mm. thick, in a split basalt block encased in cement; this is turbulent flow. I is the lower end of Run No. 25 (G) which shows steadily augmented reduction of flow in relation to head, with N reaching apparently as low as 0.10. This run developed much film formation and probably electrokinetic retardation and led presently to studies of the time effect. Scales are as indicated, in order to condense on one diagram.

ment . . . Gravels may in all cases be traced upslope to their source beds. Loess creeping over gravel layers picks up stones and incorporates them in the process of carrying them downslope" (p. 20).

The criticism attaches significance to "churning movements" that I did not emphasize, as may be appreciated from the fact that in my summary of the process of loessification (p. 30) no reference to churning occurs. The churning mentioned is the type commonly recognized by pedologists, contrasting with laminar translocation. It is well known that such movements cause the rise of larger particles to the surface, whether churning be caused by alternating freezes and thaws, the growth of plants, or the creep of soil and similar materials down slopes.

After quoting me to the effect that "Surface losses of fine material occur for various reasons" the statement appears that "The 'various reasons' might include wind action, but the attempt is to avoid appeal to eolian processes." My statement refers to processes responsible for concentrating coarser particles residually. Wind appears to play an important part in leaving residual desert pavements in the arid Southwest. It may play a similar rôle in the lower Mississippi Valley when it raises dust, but residual concentration of coarse particles is not an essential part of the eolian hypothesis of loess origin. The hypothesis is concerned primarily with deposition. "It seems improbable that either wind or water could move with the uniform velocity required to permit the accumulation of material so homogeneous that at least half and ordinarily about three-fourths of its particles (by weight) fall within the limited diameter range 0.01-0.05 mm." (p. 24).

The discussion "Problems of mineralogy" refers mainly to observations that may be checked as to factuality. Criticism based on the introduction of contradictory facts has far greater weight than that based on opinion or speculation. The assumption that calcite grains in loess are detrital is wholly at variance with any facts known to me. The secondary nature of the carbonates is clearly emphasized throughout my paper. Polynov's assertion that the mineralogical investigation of carbonates such as occur in loess is practically a virgin field for research (p. 26) is true as far as I know.

To the assertion, "No evidence that secondary-carbonate enrichment ever extended throughout the deposit classed as leached loess," I may cite, "The newer cuts along U. S. 61 south of Vicksburg display deloessification zones many feet thinner than those along old roads in the vicinity. The zone is always thickest on the face of a cut, and ordinarily its base slopes sharply upward in the first few feet . . . Effective leaching removes carbonates, shells dissolve completely, root tubes suffer various degrees of destruction, and aggregates start breaking down . . . All features related to competence gradually disappear" (p. 33).

of decreasing head positions is accompanied by an apparent shift in the zero position, by which zero flow is reached before zero head is reached, followed by reversed flow which increases before the previously determined hydraulic zero is reached. This effect was shown to operate in either direction, and was found later to be dependent on lack of an electrical ground so that an electrostatic charge is built up. This is by no means a mere stoppage; it is an actual electrokinetic potential, apparently due to the streaming effect, and which is capable of inducing flow against an equivalent hydraulic potential.

To further test this, in Run No. 127, by rapid succession of flow rates from 30 cm. head downward, in a basalt crack 0.1 mm. thick, a potential equivalent to 2.25 cm. was established, after which, with the head of the supply jar very slightly lowered, the water flowed for more than four hours against a hydraulic head of over 2.0 cm. and moved a total of more than 10 cc. of water.

Many different runs were made which demonstrated the reduction of flow rate with time and to economize space, the chief characteristics of 15 runs of this kind are summarized in the following table.

Table of Flow Behavior in Thin Cracks.

Run No.	Wall	Thickness (mm.)	Liquid	Total Time (Minutes)	Total Ratio of Reduction	Reduction Ratio per 100 minutes	End Condition (2)
106	Rock	.045	Tap water	1275	205	1.52	C–1440
107a	"	"	" "	1090	48	1.43	disturbed
107b	"	"	" "	1410	22	1.24	C–890
107c	"	"	" "	2120	11	1.12	C–640
110	"	"	" "	1335	56	1.35	C–3525
111	"	"	" "	2180	244	1.29	C–470
115	Brass	.026	" "	290	19.4	2.78	n. r.
116a	Rock	.045	Dist. water	2160	246	1.29	C–645
116b	"	"	" "	1310	150	1.46	n. r.
117	Brass	"	" "	2780	2740	1.33	C–5470
119	Rock	(1)	Benzol	570	17	1.64	n. r.
120	"	.045	"	1440	10	1.17	C–980
121	Brass	"	Dist. water	980	1850	2.15	n. r.
122	"	.232	" "	642	51	1.84	n. r.
123	"	.464	" "	1218	9300	2.12	n. r.

(1) In this run the rock surfaces were tightly in contact; the opening was due to irregularity and its dimensions were small but unknown.

(2) In this column, for example, C–1440 signifies that the flow continued at a constant rate for 1440 minutes additional to the total time of reduction shown in column 5. The designation n. r. means no record was made.

My paper would have been strengthened by the inclusion of grain-sized analyses of backswamp deposits. At the time of writing it seemed sufficient to include only a typical loess-like sample from the lowest terrace and a sample of material that has almost become loess on a slope leading from an upper terrace. The ratio clay to silt in backswamp clays is by no means as high as the term clay would ordinarily lead one to believe, and I regret that my paper is not sufficiently emphatic on that point.

The problem of disposal of fine material is not difficult. No significant topographic changes are required. Most of the sorting goes on while A-horizons are being developed in parent materials. The concentration of coarse particles in A-horizons is characteristic of most mature soils and is mainly the result of translocation of finer particles to B-horizons below. Mass movements on slopes leading to loess deposits affect mainly the surface, where coarse particles have accumulated residually. Concentration of coarse particles is characteristic of colluvial phases of most soils. These processes explain the concentration of silt in loess, whereas finer materials are left behind in the subsoil horizons of parent material areas. These places are topographically higher than those where loess accumulates. The quantitative aspects of the problem are not serious. Slopes of parent material are widespread in the loess belt but individual deposits of loess are relatively small.

The statement that I offer but two facts in support of colluvial origin of loess appears unfair. That one of them is the tail of fine grain sizes extending far beyond the coarse silts that constitute an overwhelming proportion of each sample is an interpretation that I did not anticipate. This fact was stated quite incidentally, rather than as a vital link in an argument. I regard it as confirmatory and believe that practically all sedimentologists will agree that it indicates sorting of the type described. The weight of the evidence in support of colluvial origin lies mainly in conclusions derived from intensive field work in stratigraphy. Laboratory investigations confirmed gradations noted in the field. Pedogenic theory appeared to be favorable to conclusions reached. A rather thorough investigation of literature yielded many confirmatory observations and little valid contradictory evidence Personal familiarity with many European loess localities helped provide background for the major thesis presented.

The statement, "No field or laboratory fact cited seems to disprove eolian origin for loess in the lower Mississippi Valley" appears to indicate complete disregard for most of the observations on which my paper is based. Is it possible to explain the distribu-

In the foregoing table, the broad fact of flow reduction is clearly shown with retardation of more than 1000 fold in three runs. In the seventh column is shown for each run a computed rate of reduction per 100 minutes, which in general falls between 1 and 2. As shown in Fig. 5, the general course of reduction is that of a logarithmic decrement, giving a straight line when

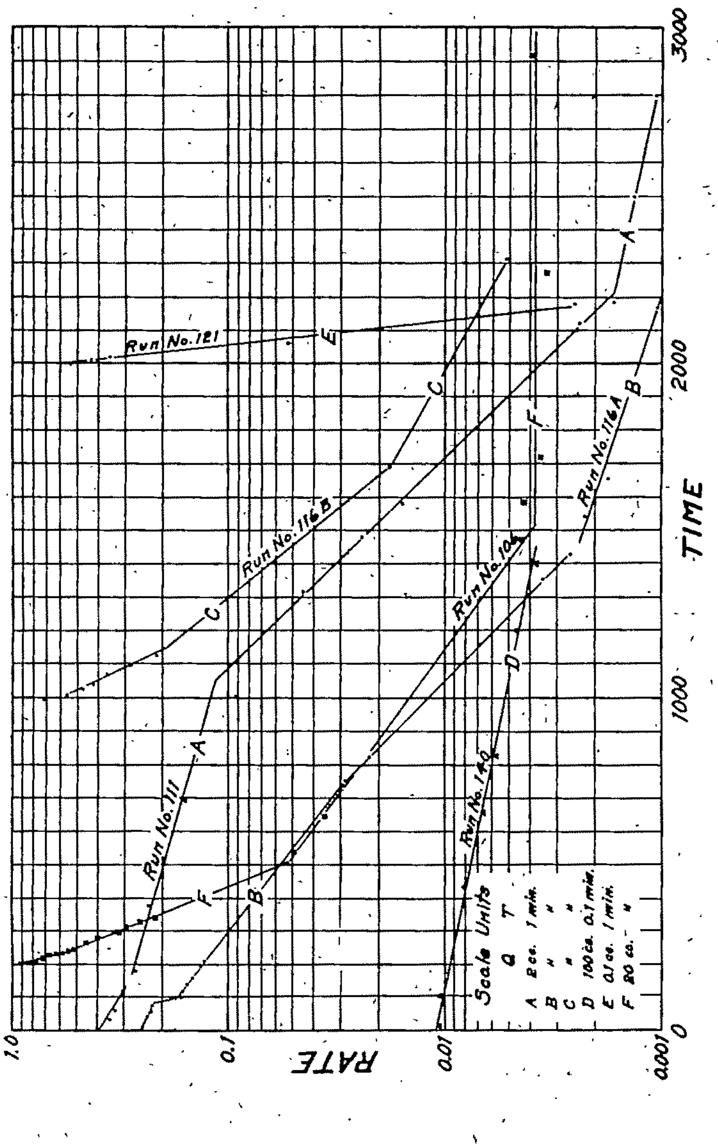

Fig. 5. Graphs showing rate plotted against time for runs made under various conditions. Note particularly the straight line distribution of points for all or parts of various run. Scale units have been chosen in order to place the runs on the graph; absolute slope in any case is significant only if scales are taken into account. Line D, Run 140, is for flow through medium coral sand, under 9 cm. head, in a jar of 9 centimeter length, with cross-section of 64 square centimeters. Data for the other lines will be found in an accompanying table.

ion, orientation, shapes, internal characteristics, and stratigraphy of loess deposits under a theory of eolian origin? A serious attempt, extending over many years, to do that very thing convinced me that it is impossible.

I refuse to accept credit for championing "a new process hitherto neglected or unknown." References in my paper show that Hilgard, Leverett, Mabry, Harris and Veatch, Todd, and Shaw saw that "loess grades into alluvial clays" (p. 26). Hilgard, Moyer, Worthen, Winchell, Chamberlin, and Todd suggested possible colluvial origin of loess. Relationships between colluvial origin and uniformity in grain size were recognized as early as 1866 by Worthen and in 1886 by Wahnschaffe. The transition to less loessial characteristics with increasing distance from bluffs was noted by both Todd and Leverett in 1897. Even the term "loessification" was suggested to me by A. Penck (p. 2).

One may not expect immediate acceptance of a thesis that runs counter to firmly established belief, however flimsy the evidence upon which the belief rests. In venturing into a position where it seemed necessary to renew an argument that appeared to be settled, I realized that various antagonisms might be aroused and brought the matter to print only after many years of careful investigation. If this venture renews an interest in field work that will lead either to the confirmation of my thesis or to other explanations even more positive and conclusive, my efforts will have been well repaid.

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plotted on semilog paper with time on the arithmetic scale. This form is approximated by many of the runs, but there are moderate deviations from the straight line in both directions in some runs.

It is also noteworthy in such plotting that commonly several points over a period of several hours will fall closely on a straight line, only to change abruptly so that subsequent points define another straight line at another slope. This behavior suggests that the rate of retardation tends to be proportional to rate of flow, but that such course may be interrupted by unrecognized changes in condition which initiate a similar decrement at a new rate. (Fig. 5.)

Among the runs shown in the table, about half were continued and recorded for periods of some hours after a constant rate had been reached. Longest of these was No. 117, in which flow was reducd from 0.03 to 0.00001 cc. per second in the course of about 47 hours, and then remained between 0.000012 and 0.000009 cc./sec. 91 hours more. A summary of these runs is presented in the following table.

Table of Terminal Rates.

Run No.	Liquid	Head (cm.)	Final Volume Rate (cc./sec.)	Final Velocity (cm./sec.)
106	Tap Water	85	.0002	.006
107b	Tap Water	10	.0002	.006
107c	Tap Water	40	.0016	.047
110	Tap Water	20	.00035	.01
111	Tap Water	20	.0006	.018
116a	Distilled Water	10	.00005	.0015
117	Distilled Water	10	.00001	.0003
120	Benzol	20	.00008	.0023

In all the above runs the thickness of crack was 0.045 millimeter and the wall in all of them was rock, except No. 117, where it was brass. In a rough way we may say that in all the runs with tap water the terminal velocity was of the order of 1/100 cm. per second or above and with distilled water or benzol it was nearer 1/1000 cm. per second. There appears also a rough correspondence with head but our data hardly warrant generalization at present.

It is very interesting that no run reached a terminal rate of

zero, and this fact leads to the speculation that possibly the terminal rate may depend on a process of net molecular interchange rather than true kinetic flow, the latter having been completely stopped. It is conceived that there is a net difference between the boundary conditions at the two ends, of the crack. (Fig. 6.) Insofar as hydraulic pressure enters into

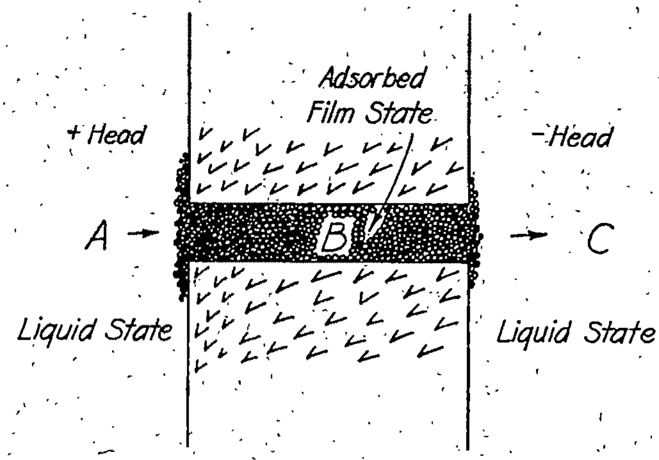


Fig. 6. Diagram suggesting conditions of diffusion through a crack in which true flow is impeded by an adsorbed molecular film.

molecular behavior across such a boundary, there will presumably be a net tendency for molecular movement to take place from A to B, and from B to C, even though this is not expressed in ordinary liquid flow. This is essentially diffusion from liquid to film to liquid which appears to continue as a residual rate of transfer after true liquid flow has stopped. Further experiment will be required to prove or disprove this hypothesis.

Summary and Explanation.

The chief findings of the experiments referred to above may be listed as follows:

(1) The flow of liquids through very small or thin openings at low velocities takes place at rates which are much less than would be deduced from Darcy's law by comparison with rates

at higher heads, or than would be deduced from the Hagen-Poiseuille law by comparison with rates in thicker openings. Superficially, the effect is as if the viscosity of the liquid were greatly increased in such openings. In some instances the final flow rate is as little as 1/1000 of the rate which would be deduced from these laws.

(2) The establishment of a final or nearly steady rate of flow in small cracks may take many hours or several days and consists of a progressive and systematic slowing down as a function of time. In the case of wider cracks, the rate may start at a value which is little if any below those consistent with the Darcy or Hagen-Poiseuille laws but after 10 or 100 hours may be reduced to 1/100 or 1/1000 of the initial rate.

(3) The condition of greatly retarded flow can be in large part destroyed by mechanical disturbance, tapping, pressure pulses, or passing water through at higher heads and velocities. For the same head the flow rate can be restored in this way to near its former value. But commonly on resuming steady flow, the retardation takes place more rapidly than before.

(4) After progressive slowing of flow through a thin crack it is commonly found that on reducing the head difference there is presently reached a point of apparent equilibrium which is several millimeters or as much as two or three centimeters above the previously determined hydraulic zero. Not only is this true but on passing beyond this point it is found that a reversed flow takes place, in which water moves toward the supply jar whose water surface is still one or two centimeters above the free surface at the normal outflow end. This formation of a potential zero differing from the previously determined hydraulic zero appears to take place only when the apparatus is not electrically grounded.

(5) The retardation effect is shown in all liquids which wetted the surface, including distilled water, tap water, solutions of boric acid and of borax, xylol, but was not observed with mercury.

(6) Though it is not the aim of the present paper to probe the application of Darcy's law at very low hydraulic slopes in permeable sediments, a few runs were made with flow through medium sand at slopes of about 1, and with velocities under 0.1 cm. per second. In these runs, as with various thin cracks, the same retardation effect was found, with flow in one case declining to less than 1/100 the initial rate in about 6 hours.

While it would be premature to attempt a discussion of this problem on the basis of limited measurements, it is puzzling that this effect was not encountered notably by Meinzer and Fishel.[3] It is mentioned in the earliest of the above papers (p. 407) that at a certain stage, "the coefficient of permeability declined to only about 200 (from 400) probably on account of clogging of the sand by some unknown cause," but otherwise no retardation was recognized. Until further tests have been made under more nearly comparable conditions, discussion will hardly be profitable, except to observe that if the writer's postulate of film formation is correct, there is no challenge to the validity of Darcy's law. The question is rather our capacity to make, interpret, and apply flow experiments in the face of the possibility that both natural and experimental conditions may be affected by the retardation here described.

Neither the writer's background, nor the apparatus available will permit a rigorous, quantitative definition of retardation. Rather it is proposed to suggest a qualitative explanation which may provoke discussion and indicate the possible bearing of this effect on ground water behavior or on hydraulic measurements in certain ranges.

The two most obvious possible causes of retardation of flow at a given head are (1) increased viscosity, or (2) decreased cross-section. The first of these possibilities was suggested many years ago in connection with retarded flow observed in capillary tubes. As then stated, it appeared "that the water dissolved from the tube a very small amount of some constituent that had an extraordinarily large effect on the viscosity at low rates of shear."[4] In these experiments the effect was eliminated when the inside of the capillary tube was silvered.

Another investigator, three years later, undertook to verify this presumed increase of viscosity at low rates of shear, using the common apparatus with concentric cylinders.[5] With this method, after experimentation, no such increase of viscosity was found. Following this result, Gurney prepared solutions from powdered glass of the same sort as the capillary tubes

[3] Meinzer, O. E., and Fishel, V. C.: 1934, Tests of Permeability with Low Hydraulic Gradients, Amer. Geophys. Union, Trans., pp. 405–409.

Fishel, V. C.: 1935, Further Tests of Permeability with Low Gradients, Amer. Geophys. Union, Trans., pp. 499–503.

[4] Duff, A. W.: 1905, Poiseuille's Law at Very Low Rates of Shear, Phil. Mag., Vol. 9, pp. 685–692.

[5] Gurney, L. E.: 1908, Physical Review, Vol. 26, pp. 98–120, 123–124.

used by Duff, which were believed to be much more concentrated than any resulting in the latter's tubes and after repeated test failed to find a significant increase in viscosity. On the other hand, in the same experiments, Gurney noted a surface rigidity of water which increased with time of standing. (Op. cit., pp. 121-122, 1908.) Such a stability of surface has been noted by others, is due to molecular film and in sum the experiments of Gurney appear to dismiss the concept of changed viscosity.

This leads to consideration of the second suggestion, a possible reduction of cross-section. The writer has suspected from the beginning of his observations of retardation that a most probable cause of such reduction of cross-section is the formation of a molecular film on the walls of the crack. This interpretation was further encouraged by the reasoning used by P. G. Nutting in connection with measurements of the rate of flow of liquids through a capillary as affected by various external molecular fields.[6] He used the rate of flow and the Hagen-Poiseuille law to deduce the effect radius of the flowing stream under different conditions and in turn the thickness of adsorbed films. No elaborate attempt was made to measure the time of formation of these adsorbed films but the first runs showed higher velocities and apparently "several minutes were required to complete the adsorbed film."

Suggestions have been made that electrolytic forces and the presence of electrolytes may be essential to the formation of the films. In view of the general presence of retardation in both distilled water and tap water and in non-conducting liquids as well as solutions of electrolytes, it does not appear that electrolytic forces are necessary, though they may play some part in certain instances. Neither is it believed that static electrical effects are essential though they appear in the polarity induced by flow when the apparatus is not grounded. The sum total of the experiments appears to indicate that the major phenomenon of retardation and the growth of retardation with time can be adequately explained by recourse only to the kinetic theory and to the molecular attractions involved in adsorption at the boundary between liquid and solid.

According to the kinetic theory, molecules of a fluid are in an incessant state of random movement, and mutual bombardment and collision, the tempo of which depends on the

[6] Nutting, P. G.: 1943, Adsorptive Forces, Active Though Glass, Science, Vol. 97, No. 2507, pp. 74-75.

nature of the fluid and on its temperature and pressure. Two of the properties of fluids, and in particular of liquids, which are to be explained by and are a necessary consequence of the kinetic theory are the equality of pressures in all directions and the tendency to flow from points of high potential to points of low potential. These properties of liquids, including that of viscous fluidity, lack of capacity to resist shearing stresses, continuous response to shearing stresses without minimum starting stress, are all fundamentally dependent on, and a necessary consequence of the random, kinetic behavior of molecules under the kinetic theory and hold in any field which is large in proportion to the dimensions and spacings of the molecules.

Contrariwise, we may say that any field composed of molecules which are actuated under the kinetic theory and in which each molecule, despite its random vectors of motion, lies indefinitely inside a statistically homogeneous field of molecular attractions and motions, is a fluid and will display the properties of a fluid. If now we consider a point within a mass of fluid, specifically a liquid, so close to a solid boundary that molecules are affected, in the direction of the solid boundary, both by the cutting off of the attraction of liquid molecules because these molecules are lacking and by the addition of attraction or repulsion of molecules of the solid boundary, we see at once that molecules of water in such a position are no longer at the center of a statistically homogeneous and symmetrical field. In the case of wetting liquids, some or all these molecules become adsorbed and form an effectively immobile film. Stated in another way, it appears that these molecules are no longer active components of a symmetrical field of kinetic behavior and no longer conform to the definition of a liquid. They have lost the properties of liquidity, including that of viscous flow. To the present writer it does not appear that more elaborate explanation is essential. Rather than to invoke increased viscosity, or forces which oppose flow in various ways, it seems more direct, as above, to point out that the very basis of liquidity is withdrawn in a mass of liquid too thin to constitute an effective kinetic field.

The thin cracks studied in these experiments consist of two nearly plane-parallel walls. It was found that when the separation becomes as little as about 1/4 millimeter, the zone on either side, next to the boundary, in which the adsorbed film is formed, is sufficiently thick in proportion to the whole crack

to be measurable. It does not appear to the writer necessary to assume that films of fixed molecules must approach 1/10 millimeter in thickness, though they are no doubt many molecules thick. It seems most likely that the transition between a fixed film and a body of fully kinetic liquid is not a dimensionless surface but a zone of sensible thickness within which the kinetic behavior of molecules must be statistically graded and unsymmetrical, proportional to the relative position. If we assume this to be the case, it will follow that near the layer of fixed molecules capture or immobilization of molecules will be imminent, and that nearer the moving stream of liquid the behavior of molecules will be more fully normal and statistically symmetrical. One of the consequences of the juxtaposition of the moving stream to the layer of assymetrical behavior and thence to the adsorbed layer would apparently be the loss of energy from the kinetic system. Since the only source of energy is the larger mass of liquid and its avenue of arrival is the stream passing through the crack, it seems reasonable to suppose that in some thin cracks the passing stream would be under low heads incapable of delivering and losing sufficient kinetic energy to remain liquid. Therefore, under the suggested conditions, the liquid filament would "freeze," through loss of energy, just as truly as would any molten substance passing through a long, thin, cooled pipe.

According to the size of the opening and the relative rates of supply and loss of energy, the opening may or may not be fully closed by the formation of an adsorbed film. This film will by no means be built up instantaneously, since it is formed of molecules which under an appropriate probability behavior fail to escape from the adsorptive force. It appears that the number of such molecules which are retained will be a function of the intensity and distribution of the adsorptive and kinetic forces integrated through a period of time. By retardation of flow through progressive constriction of the crack it appears that the absolute rate of growth of the film would be reduced but that its rate relative to the current would be approximately constant. This would produce a curve of the form of a logarithmic decrement, which is approximated by many of the experiments recorded.

The marked shift of the zero point, which causes the crack to act apparently as a pump, is due to the so-called streaming effect described in texts on electrochemistry. This is due to

the motion of water through small openings and the production of an electric potential which has been shown to be in linear proportion, under any given set of conditions, to the hydraulic head which produced it.[7] This effect apparently produces an electrostatic potential capable of moving water against small heads only when the crack and the surrounding apparatus are not electrically grounded; it probably would not be operative under natural ground water conditions but may lead to aberrant experimental results.

It is indicated by the experiments summarized here that the flow of a liquid may provide a fruitful method of measurement of the growth and mode of formation of liquid films. It is thought that such retardation of flow may be of large importance under certain conditions and that inconsistent results in flow measurements at low rates cannot be dismissed as accidental or apparatus failures. Possibilities on the practical side of ground water hydrology will be presented at a later date. Meantime it is hoped that the more precise experimental and theoretical studies of this phenomenon will be made by those experienced in molecular physics and having adequate laboratory facilities.

[7] Weiser, H. B.: 1939, Colloid Chemistry, p. 207.

HONOLULU, HAWAII.

SOLFATARIC ALTERATION OF ROCKS AT KILAUEA VOLCANO.

GORDON A. MACDONALD.[1]

ABSTRACT. Solfataric alteration of basaltic lava and vitric-crystal ash at Kilauea Caldera has produced a rock composed largely of opal, with a little kaolin and relict ilmenite and magnetite. The replacement is approximately of equal volume to the original rock. Original structures and textures are excellently preserved. The alteration resembles that in areas of acid emanations in other volcanic districts. Less abundant is an alteration to limonite and goethite.

INTRODUCTION.

At two places along the boundary faults of Kilauea Caldera escaping sulfurous gases have produced a profound alteration of the rocks. The best known of the two localities is Sulfur Bank, situated on the northern edge of the caldera near the Volcano Observatory and Volcano House. For many years the vapors of the Sulfur Bank solfatara have been used for sulfur-steam baths. The other locality is on the southeastern edge of the caldera near the southern end of Byron's Ledge, about a mile east of Halemaumau (Text Fig. 1). At those places the surficial rocks have been changed from the prevailing gray to glaring cliffs of pale creamy-yellow or grayish-white color, with minor amounts of brilliant red iron oxide and yellow sulfur. The picturesque qualities of the scene are heightened by drifting plumes of steam. Visible alteration is greater at Sulfur Bank than at the solfatara on the eastern edge of the caldera, but a large portion of the latter has been buried by recent lava flows. Lesser amounts of alteration occur at other localities, as, for instance, along innumerable cracks in the lavas of historic age which cover the floor of the caldera.

The two major areas of solfataric alteration are essentially alike. Suites of specimens from both have been examined, but they are so similar that there appears to be no need of describing both localities. The gases issuing at Sulfur Bank have been analyzed, whereas those from the other locality are known

[1] Published by permission of the Director, Geological Survey, U. S. Department of the Interior.

Fig. 1.

The middle cliff at Sulfur Bank, showing the bleached rocks much altered by solfataric gases. The darker cliff in the background is the northern cliff, forming the outer border of the graben.

Fig. 2.

The much altered middle cliff at Sulfur Bank, with the northern cliff behind it, and the floor of the graben, transected by a large fissure, in the foreground. The house covers the drill-holes from which the analyzed gas samples were collected.

only in a very general manner. For that reason, the Sulfur Bank locality has been chosen for detailed description.

The rock alteration has been attended by abundant deposition of minerals in open spaces. Many cavities are lined with well-formed acicular crystals of sulfur, some of them two inches or more in length. No study of the deposited minerals has been made by the writer, but they are known to include opal, alum, gypsum, mirabilite, kieserite, epsomite,[2] and aphthitalite.[3]

The writer wishes to thank Mr. E. G. Wingate, Superintendent of Hawaii National Park, for permission to collect specimens for scientific study within the boundaries of the Park. R. H. Finch, H. T. Stearns, and C. K. Wentworth have kindly criticized the manuscript.

GENERAL GEOLOGY.

Kilauea Caldera is a great sunken area at the summit of the broad shield volcano of Kilauea. The boundaries of the caldera are a series of faults, which appear to be essentially vertical. Nowhere, however, is the boundary a single fault. On all sides, the displacement is accomplished by a succession of offsets, the greatest of which is generally the innermost (Text Fig. 1). The fault scarps expose a series of lava flows, ranging in composition from olivine-poor basalt, through olivine basalt, to picritic basalt very rich in phenocrysts of olivine.

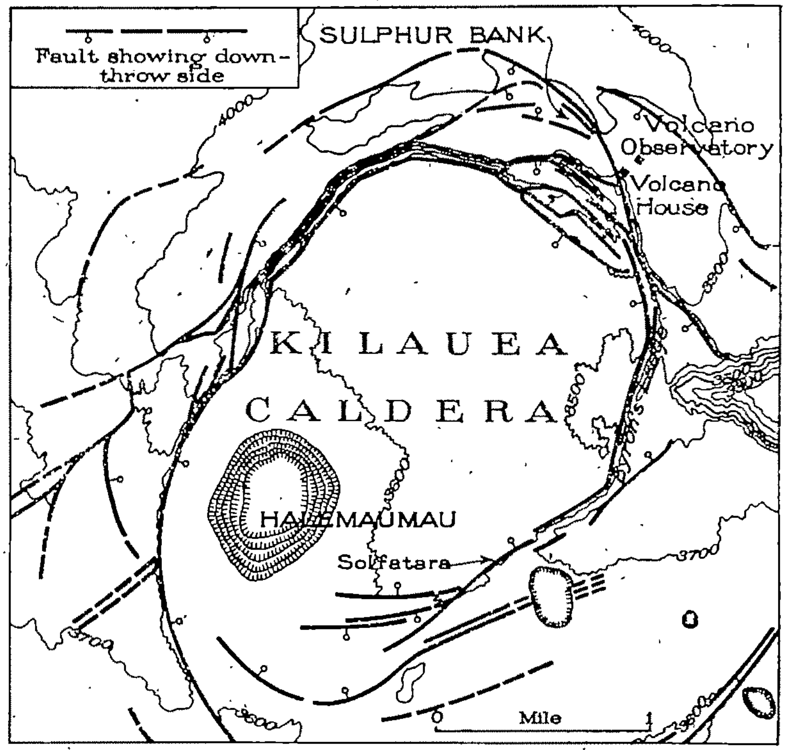
Sulfur Bank occupies the northern wall of a shallow graben just within the outermost fault at the northern edge of the caldera. The northern wall of Sulfur Bank consists of two faults, the outermost of which forms a cliff 30 to 50 feet high, and the other a cliff 15 to 20 feet high. The southern boundary of the graben is a low cliff 5 to 15 feet high. Gases escape along all the faults, but are most abundant along the middle one. The entire area between the northern and middle faults is much fractured, and vapors issue at many points. Alteration is greatest along the middle fault and in the block between it and the northern fault. The distribution of altered rock and deposits of sulfur and salts, indicates that solfataric activ-

[2] Moomaw, B. F.: 1938, The rocks and minerals of the Kilauea-Mauna Loa Section of Hawaii National Park, Hawaii Nat. Park Natural History Bull. 8 (mimeographed), p. 20.

[3] Washington, H. S., and Merwin, H. E.: 1921, Aphthitalite from Kilauea, Am. Mineralogist, vol. 6, pp. 121-125.

ity was once more extensive than now. Some migration of the active vents occurs.[4]

The cliffs at Sulfur Bank expose a series of thin flows of olivine basalt and olivine-poor basalt, principally pahoehoe, overlain by a layer of ash 3 to 5 feet thick. Both the lavas



Text Figure 1. Fault map of Kilauea Caldera, showing the location of the principal solfataric areas (slightly modified after Stearns, H. T., and Clark, W. O.: Geology and ground water resources of the Kau District, Hawaii, U. S. Geological Survey, Water Supply Paper 616, plate 1, 1930).

and the ash are greatly altered. The ash appears to alter more readily than the lava, however, probably because of its higher content of unstable glass.

COMPOSITION OF THE SOLFATARA GASES.

The gases escaping at Sulfur Bank have been studied by

[4] Finch, R. H.: 1943, Personal communications, November 4.

several workers. In 1922, E. T. Allen collected samples of gas from drill-holes at Sulfur Bank. His analyses yielded the following composition for the fumarole gases:[5]

Steam	96.2 %
Fixed gases	3.7
Sulfur dioxide	.096
Sulfur vapor	.004
Hydrochloric acid	trace

The temperature was found to be 95.5° C., or approximately the boiling temperature of water at that altitude, throughout the depth of the drill-holes. Earlier partial analyses by Brun[6] had detected no sulfur dioxide. Studies by Ballard and Payne, during 1936 and 1937,[7] showed that the fixed gases detected by Allen probably consisted of air and carbon dioxide.

Further studies by Ballard and Payne, on a series of 43 samples collected at short intervals from September 1938 to August 1940,[8] showed sulfur dioxide to vary greatly in amount. No combustible gases were detected except during March and April, 1940, when hydrogen sulfide was present in very small amounts. The present writer thought he could detect a faint odor of hydrogen sulfide at times during July and August, 1941. The values determined by Ballard and Payne, for constituents exclusive of steam, are summarized below. That for sulfur dioxide includes a very small amount of hydrogen sulfide during March and April, 1940.

	Average	Range
Air	7.9%	0—40%
Sulfur dioxide	4.6	0.5—18
Carbon dioxide	88.1	49.2—99.5

Obviously, the gases are weakly acid. Condensation of steam at and near the surface produces a film of moisture on exposed surfaces of the rocks. The dissolving of small amounts of carbon dioxide and sulfur dioxide, with partial further oxidation of the latter, produces a weak solution of carbonic, sulfurous, and sulfuric acid, which vigorously attacks the rocks.

[5] Allen, E. T.: 1922, Preliminary tests of the gases at Sulphur Banks, Hawaii, Hawaiian Volcano Observatory Bull., vol. 10, pp. 89-93.

[6] Brun, A.: 1911, Recherches sur l'exhalaison volcanique, p. 251, Paris.

[7] Ballard, S. S.: 1938, The volcanic gas problem, Volcano Letter, no. 455, pp. 1-5, January.

[8] Ballard, S. S., and Payne, J. H.: 1940, A chemical study of Kilauea solfataric gases, 1938-40, Volcano Letter, no. 469, pp. 1-8, July-September.

ALTERATION OF LAVAS.

Megascopic features.—At Sulfur Bank, lavas exposed in the low fault cliffs exhibit various stages of alteration. The rocks are divided by joints into polygonal blocks a few inches to a few feet in diameter. The joints provide the easiest avenues for migration of the gases, and consequently the rock along the joints is most altered, whereas that in the center of the blocks is least altered. Some blocks have been affected throughout, but in many there still is preserved an unaltered or little-altered core. Penetration of the agents of decomposition has been greatest at the corners of the joint blocks, resulting in rounding of the residual, unaltered core, as in ordinary spheroidal weathering. The discrete concentric shells resulting from volume change on decomposition, which are characteristic of spheroidal weathering, are absent, however. Typically, a partly altered joint block consists of a core of dark gray, fresh-appearing lava, surrounded by a zone in which the color becomes lighter and lighter, until at the edges the rock is bleached to a pale creamy-yellow or grayish-white. The glassy crusts of pahoehoe flows appear to alter more readily than the lithic interiors.

Even in the most highly altered lavas, the primary structures are still clearly visible. The highly vesicular structure of frothy pahoehoe is perfectly preserved, as also are ropy pahoehoe flow tops.

The overlying ash deposits are even more generally altered than the lavas. The original colors of the ash were greenish-brown, buff, or gray, but they are now largely pale cream in color. The original fine lamination characteristic of the fresh ash is well preserved.

Another type of alteration, extensive in the ash but generally confined to thin seams in the lava, consists in an extreme reddening of the rock. The red alteration occurs in more or less distinct patches, being abundant in some small areas, and nearly or completely absent in adjacent areas.

Microscopic features.—Successive zones, from the unaltered cores of joint blocks to the highly altered and bleached rims, have been studied in thin section. The fresh rock of the cores is a basalt of a type common at Kilauea. A few phenocrysts of olivine, up to 1 mm. long, and rare microphenocrysts of plagioclase, up to 0.3 mm. long, lie in an intersertal groundmass with an average grain size of about 0.05 mm. The olivine

phenocrysts have a $-2V$ close to 90°, indicating a fayalite content of about 20 per cent. The groundmass consists of labradorite, pigeonite, magnetite, ilmenite, and interstitial glass. Ilmenite is more abundant than magnetite. The glass is pale brown where clear, but is generally rendered black and opaque by abundant iron ore dust.

Even in the cores of the joint blocks, the rock is largely altered around vesicles and any other openings which permit the easy movement of gases. In detail, the boundary between the fresh and altered rock is gradational, but the transition is completed within a zone about 0.1 mm. thick. No evidence of preferential alteration of feldspar or pyroxene is seen. Within the transition zone grains of either mineral may survive imbedded in altered rock. Magnetite and ilmenite appear to be the least affected of the primary constituents.

Many of the vesicles in the cores of the joint blocks are lined with zeolite, which generally contains many small flakes of muscovite, and a little chlorite and epidote. Locally zoisite, in well formed crystals, is abundant. At such places the zoisite occurs largely along the edge of the vesicle, passing inward into a mixture of zeolite and muscovite. The zeolite has $+2V=50°\pm$, $r > v$ distinct, and $\beta=1.525$ ($\pm.003$). It is probably thompsonite.

The pale gray zone, surrounding the unaltered core, is very largely altered, but the intersertal texture of the original rock is still clearly visible in ordinary light. The feldspar microlites are clear and nearly colorless, whereas the areas formerly occupied by pyroxene and glass are grayish-brown and turbid. The iron ore appears to have been little affected. It is still present both as small individual grains of magnetite and ilmenite, and as a fine dust in the originally glassy areas, which are thereby made black and opaque in transmitted light. The vesicle linings consist of zeolite, zoisite, and epidote. The main mass of the rock consists very largely of isotropic opal. Associated with the opal are many small grains of kaolinite, or a related mineral. Rare grains of olivine and pyroxene are still preserved, but the feldspar appears to be entirely destroyed. A few former olivine phenocrysts are altered partly to reddish-brown limonite and partly to opal. The texture of the rock is so perfectly preserved that it is surprising on crossing the nicols to view an almost totally dark field.

The outermost rims of the joint blocks, although bleached

almost white, show in thin section little difference from the intermediate zones of light gray color. The rock is largely opal, with many small grains of kaolinite, or a related mineral. The iron ore, particularly the ilmenite, is still largely preserved, although some of the fine dust which was scattered through the original glass appears to have been removed. The minerals which characteristically line the vesicles in the inner zones have not been found in the outer, bleached zone, but instead, crystals of sulfur are commonly present. The rock is a little more porous than that of the inner zones, but the original texture and structures are still excellently preserved.

Ash deposits overlying the lavas are altered in a precisely similar manner. In their fresh state, the surficial ash beds surrounding Kilauea Caldera are largely vitric-crystal tuffs, composed principally of fragments of basaltic glass, in and among which are scattered phenocrysts of olivine and a few microlites of labradorite and pyroxene. Lithic lapilli are occasionally found, and small fragments of pumice, derived from the lava fountains at the sources of flows, are quite abundant. Like the lavas, the ash at Sulfur Bank is altered to an aggregate consisting very largely of opal, with a few small grains of kaolinite. Even in the most highly altered material, however, the original structure of the ash is clearly preserved. Both the forms of mineral fragments and the characteristic arcuate outlines of glass shards can be easily recognized. Small lapilli of pumice, and others of intersertal basalt, all completely opalized, are readily distinguishable.

The red alteration in the ash, and in thin seams in the lava, produces a soft, powdery substance which consists largely of isotropic limonite, with a few flakes of birefringent goethite, some kaolinite, and scattered residual grains of the original rock-forming minerals. The alteration appears to consist in the oxidation and hydration of the iron, leaching of part of the alumina and hydration of the remainder, and leaching of most or all of the other components.

Chemical changes.—In 1896, Maxwell collected and analyzed specimens of fresh and altered lavas along steaming cracks on the caldera floor, and altered lavas at Sulfur Bank.[9] The analyses are incomplete and appear probably unreliable, and

[9] Maxwell, Walter: 1898, Lavas and soils of the Hawaiian Islands, Investigations of the Hawaiian Experiment Station and Laboratories, Hawaiian Sugar Planters' Association, pp. 12-13, 18-19, Honolulu.

will therefore not be quoted in full. They do, however, demonstrate the general nature of the changes involved. The fresh lava contained 49 per cent silica, whereas a partly altered specimen of the same rock contained more than 55 per cent silica, and a still more altered specimen more than 62 per cent. Of the specimens of the white, altered material from Sulfur Bank, one contained 67 per cent silica, and another nearly 76 per cent. A specimen of the red material contained 44.5 per cent ferric oxide, and only 32.5 per cent silica.

CONCLUSIONS.

Alteration of olivine basalt lava and ash at the solfataras at Sulfur Bank and on the eastern edge of Kilauea Caldera has produced rocks composed very largely of silica, in the form of opal, with a lesser amount of kaolinite. The alteration closely resembles that in the areas of acid emanations at Lassen Volcanic National Park,[10] Sulfur Banks at Clear Lake, California,[11] and Yellowstone National Park.[12] Although the original rocks differed widely in composition, being basalts at Kilauea, basalts, andesites, and dacites at Mount Lassen, andesite at Clear Lake, and rhyolite in Yellowstone Park, the products of alteration in all four areas are very similar. At Kilauea, labradorite, pyroxene, and olivine are altered with approximately equal ease, but magnetite and particularly ilmenite are much more resistant, and persist in nearly their original amounts even in the most highly altered rocks. Magnetite and ilmenite likewise were found to be the most resistant minerals of basalt under the weakly acid conditions of weathering which produced certain ceramic clays in high-level swamp areas in Hawaii.[13]

Olivine-poor basalts of Kilauea, like that which constituted the original rock at Sulfur Bank, contain approximately 51 per cent silica, 13 per cent alumina, 11 per cent iron oxide, 7 to 8 per cent magnesia, 11 per cent lime, 2 per cent soda,

[10] Anderson, C. A.: 1935, Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park, Am. Mineralogist, vol. 20, pp. 240-252.

[11] Anderson, C. A.: 1936, Volcanic history of the Clear Lake area, California, Geol. Soc. American Bull., vol. 47, 649-651.

[12] Allen, E. T., and Day, A. L.: 1935, Hot Springs of the Yellowstone National Park, Carnegie, Inst., Washington, Pub. 466, 100-101.

[13] Wentworth, C. K., Wells, R. C., and Allen, V. T.: 1940, Ceramic clay in Hawaii, Am. Mineralogist, vol. 25, pp. 1-33.

and 0.5 per cent potash. The opaline rock resulting from the solfataric alteration consists almost entirely of hydrated silica, with small amounts of iron oxide, alumina, and potash. Most of the magnesia, lime, and soda, and much of the alumina and iron oxide, have been removed. If not compensated by other factors, the loss should entail considerable decrease in volume of the solid portion of the rock, resulting in either greatly increased porosity or a collapse of the remaining rock. Neither has occurred. There has been no collapse, and the increase in porosity is at most only slight. Primary structures and textures are excellently preserved, even in microscopic detail.

Part of the loss has been compensated by the addition of water, and the rest is probably largely compensated by the decrease of approximately one-third in the specific gravity of the material composing the rock. There may, however, have been some addition of silica by the rising gases. The gases are known to transport at least small amounts of silica, as is shown by the occurrence of opal in some of the open spaces, associated with salts deposited by the escaping vapors. Opal has been found also in depositional crusts formed along steaming fissures in the 1919 lava, on the floor of Kilauea Caldera. Whether the silica was derived by decomposition of rocks deeper down along the passages of migration of the rising gases, or whether it represents material transported from the underlying magma body by the juvenile fraction of the gases, is not known. That the primary gases escaping from underlying masses of magma in the Hawaiian province may carry with them silica is suggested, however, by the widespread deposition of chalcedony and quartz in open spaces in the lavas occupying the deeply dissected vent areas of the East Molokai Volcano, and the Koolau Volcano on Oahu.[14]

In close contiguity to the above type of alteration, and contrasting sharply with it in nature, is another less prominent type in which silica and most other constituents are removed, iron oxide, and to a lesser extent alumina, being passively concentrated. The difference is probably the result of differing concentrations of sulfuric acid. Where sulfuric acid is strong both iron and aluminum are taken into solution, along with

[14] Stearns, H. T., and Vaksvik, K. N.: 1935, Geology and ground water resources of the island of Oahu, Hawaii, Hawaii Div. of Hydrography, Bull. 1, p. 88.

the other bases, leaving a residuum composed largely of silica. Where acidity is low, because of either dilution or partial or complete neutralization of the acid, little iron is taken into solution, or iron may be precipitated.[15] Rain water moving downward along cracks may dilute the acid sufficiently to cause precipitation of hydrous iron oxides as films along the cracks. Elsewhere, a particularly abundant supply of meteoric water, or an unusually small supply of rising acid gases, may result in solutions so weakly acid that the iron and part of the aluminum are left behind as hydrous oxides, the other constituents being partly or wholly removed as in the lateritic weathering normal to the wet regions of Hawaii. In these red patches the acid is probably of relatively small importance in the rock decomposition, but the high temperature prevalent throughout the solfataric area greatly accelerates rock decomposition as compared to that in nearby cold areas.

[15] Allen, E. T.: 1935, quoted in Anderson, C. A.: Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park, Am. Mineralogist, vol. 20, p. 251.

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BRUSH FIRES AND ROCK EXFOLIATION.

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THE heat of forest fires has been recognized generally as an effective agent in producing rock exfoliation (Blackwelder, 1927[1]), but little mention has been made of brush fires in this capacity. In the months of November and December, 1943, several square miles of brush and grass land in San Diego County, California, were burned over. In the areas having thick soils, the main geological result is probably an increased rate of erosion by rain wash. On steep hillsides where rock

Fig. 1. Exfoliated rock surfaces developed by heat of brush fire. Note the contrast between the blackened original rock surface and the white patches of freshly exposed rock. Just to the left of the hammer is a boulder with a slightly blackened patch marking the position of a spall broken off during the fire. Rocks in the foreground show a number of loosened but not completely detached spalls.

[1] Blackwelder, Eliot: 1927, Fire as an agent of exfoliation: Jour. of Geol., vol. 35, pp. 134–140.

crops out, exfoliation of rock surfaces was an additional effect. This was very marked in an area of quartz diorite near Lake Hodges, where the brush consisted chiefly of manzanita and sugar bush (*Rhus ovata*). Spalling exposed large patches of the fresh white rock beneath the blackened original surface (Fig. 1). Much of the blackened surface also consisted of detached spalls which had not yet fallen clear of the rock mass, as shown in the foreground of Fig. 1. More than 50 per cent of the original surface of many boulders and outcrops was thus removed.

Many of the spalls were roughly circular in shape, but most were irregular. Some were as great as two feet in diameter. They had a thickness of $1/8$ to $2\frac{1}{2}$ inches near the center and tapered to sharp edges. Locally, the spalls were abundant enough to form sizable piles around the larger boulders (Fig. 2). However, some spalls lay more than 5 feet

Fig. 2. Showing a pile of rock spalls such as commonly present around large rock masses.

from the closest large rock mass, indicating that they were thrown off with considerable force.

Many of the freshly exposed surfaces, both of the rock and the spalls, were slightly blackened, in contrast to the very black original surface, indicating that fracturing took place during the fire but evidently in the later stages. No evidence of chemical weathering was observed on freshly exposed surfaces, while weathering of the original rock surface was generally restricted to a slight cloudiness of the feldspar grains.

Spheroidal shapes are characteristic of quartz diorite outcrops in the region and further development of these shapes resulted from the exfoliation by the fire, since the thickest spalls were generally formed at the sharpest corners. Loosely attached to a few of the rocks were older but very similar spalls, suggesting that the spheroidal shapes of the rocks were partly due to previous brush fires. No evidence was found indicating recent splitting of boulders into large fragments along planes through the center, and thus forming more angular blocks. Apparently, the heat developed by the fire was sufficient to affect only the outer surface.

Since the heat even of a brush fire can produce extensive exfoliation, and since large areas of the west have a brush cover, it seems not unlikely that a great deal of exfoliation has resulted from brush fires, with the consequent tendency toward development of spheroidal rock shapes in widespread areas.

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DISCUSSION.

CONTINENTAL DRIFT, EIN MÄRCHEN

In the April number of the AMERICAN JOURNAL OF SCIENCE, my well-balanced colleague, Chester R. Longwell, who leans neither backward nor forward in scientific discussion, analyses the evidence for continental drift, adopting what seems to be a most cautious attitude of skepticism. I would like to join him on the fence, but I cannot. I confess that my reason refuses to consider "continental drift" possible. This position is not assumed on impulse. It is one established by 20 years of study of the problem of former continental connections as presented by Wegener, Taylor, Schuchert, du Toit, and others, with a definite purpose of giving due consideration to every hypothesis which may explain the proven facts. But when conclusive negative evidence regarding any hypothesis is available, that hypothesis should, in my judgment, be placed in the discard, since further discussion of it merely incumbers the literature and befogs the minds of fellow students.

It is my firm conviction that the laws of mechanics and dynamics govern terrestrial structures in their developments and movements, whatever the magnitude of the masses and forces involved. Continents present no exception. The following is a test in point. The original postulate of the theory of Continental Drift is that South America drifted away from Africa to a distance of 2,000 miles at a rate of westward progress sufficient to push up the Andean mountain chain. Wegener says (page 8, 3rd ed.) "By the westward drift of the two Americas, their anterior margin was folded together to form the mighty range of the Andes as a result of the opposition of the well-cooled and therefore resistant floor of the Pacific." Now, it is a well-established principle of mechanics that any floating object moving through air, water, or a viscous medium creates behind it a suction of the same order as the pressure developed in front of it. This law applies equally to airplanes, ships, rafts, and drifting continents (if there are any). The pressure which could raise the Andes must, therefore, have been approximately equaled by the suction and tension in the rear. Sections of the continent must have been sucked off. They should now remain as islands in the Atlantic; but there are none such. Moreover, if such segments had been pulled off, the eastern outline of South America should not so closely resemble the other side of the supposed original fracture.

The close similarity of the two coasts presents us with the choice: either the laws of dynamics were suspended to preserve unaltered

the rear outline of the drifting continent or the continent did not drift.

Any engineer, confronted with the task of moving a continent, might well inquire by what force? Wegener suggested two: a tendency from the poles toward the equator and a "westward drift." The former is quite inadequate and should have been satisfied in early stages of adjustment, a thousand million years before the suppositious displacement, if ever. The second he merely infers, saying: "The westward drift of the continent becomes still clearer by a study of the map of the world. The large blocks move westwards in the sima." He does not say why (pages 191-192) Du Toit frankly faces the problem, but leaves it unanswered. Referring to the assumed break up of the hypothetical Gondwana continent he says: "The precise mechanism is not readily visualized." After assuming the extension of rift valleys into the continental mass, he remarks that "sliding began;" he does not, however, explain the conditions producing sliding, but concludes: "The dispersion of the continental fragments must have been a highly complicated business and not one lending itself to full mathematical analysis." This is begging the question. In general the attitude of advocates of the Theory is that since continents did drift there must have been some competent mechanism of some kind.

Fellow scientists who are not geologists cannot be expected to know that the geology upon which protagonists of the Theory rest assumptions is as antiquated as pre-Curie physics. Wegener and his successors are disciples of Edouard Suess, the Master of European geologists. I knew him well: a charming, genial German, who never traveled far, but assembled the observations of others and from them constructed speculations regarding the face of the Earth. His reading was prodigious, his memory marvelous, his imagination grand; but he gravely lacked critical faculty. And when some airy concept had grown in his mind, it became too firmly rooted ever to be dislodged.

Such a concept was Gondwana Land, the continent supposed to have extended from the East Indies westward to the Pacific, embracing India, Africa, and South America and occupying the sites of the Indian and South Atlantic oceans. It had no actual extstence. It was conceived to account for the transoceanic migrations of plants and terrestrial organisms, the identical line of reasoning of the argument for Continental Drift. In Suess's imagination, it was a reality; but there is no reality, no geologic fact to demonstrate the one time existence of such a mass as it would need to have been.

Charles Schuchert, our great paleontologist, was also a disciple of Suess and believed in Gondwana Land till convinced on the

evidence of modern geologic research that no such expanse of continental nature could have existed and have so completely disappeared. He eventually modified its outlines to those of a narrow land bridge or bridges, as stated in his paper, Gondwana Land Bridges, 1932.

Wegener followed Suess in the assumption that the Pacific is older than the Atlantic and upon that postulate based the concept that it had cooled further and become stiffer. Therefore it offered the resistance that stopped South America and folded up the Andes. This is mere wishful thinking. No one knows which of the two ocean basins is older; they may be more or less contemporaneous. But it is known that there was pronounced activity in and around the Pacific basin during the late Mesozoic and Tertiary eras, at the time when drifting South America should have been stopped by the congealed ocean bed. And it is also true that similar activity in the Atlantic realm had ceased more than 100 million years earlier. The facts are just the reverse of the postulates.

Furthermore, the assumption regarding a deep continental mass or block is erroneous. Wegener wrote (p. 4): "It is assumed that the continental blocks, with a thickness of about 100 km., swim in a magma out of which they only project about 5 km., and which is uncovered in the floor of the oceans." It is now known on seismological evidence that the granite of which continents chiefly consist has been erupted in a number of more or less contiguous bodies, at different times, some of them quite recently. The molten granite has come up from and rests on top of a general basaltic shell, and varies from 8 to 30 kilometers, more or less, in thickness. It may be described as a scum, like slag as it were. It completely lacks the unity, the solidity of a "block." It could not drift except as flotsam in a current of the basaltic sima, which according to hypothesis and in fact did not flow.

Thus the theory of continental drift is a fairy tale, ein Märchen. It is a fascinating fancy which has captured imaginations. It is one of a long line: Werner's hypothesis of the sedimentary origin of all rocks by precipitation from a universal ocean, which the charm of his personality and the force of his conviction maintained for forty years; Suess's pure assumption that there is no force stronger than gravity and any broad uplift of a part of the earth's crust an impossibility, which was disproved when W. M. Davis demonstrated the uplift of central Asia on physiographic evidence that is now beyond dispute; Lugeon's concept of the nappes de recouvrement by which the Alps were piled up to 40,000′, which was based on assumed simplicity of pressures and mistaken postulates of folding in lieu of shearing. They challenge by their stupendous appeal to the imagination and by the implication that there is no other explanation.

In the case of Wegener's theory, I think there is. The biological, botanical evidence of migrations by land where no land now is must be accepted as conclusive. But what is land? Let us define it as an area of the earth's surface which stands at present above sea level, or which in some former age was land when it so stood. For dynamic reasons areas of granite commonly rise to that position; but the lifting force must develop beneath them and may equally well develop beneath an area of the basaltic ocean bed.

Is the relation to sea level a permanent condition? There is abundant evidence in marine fossils raised to high altitudes and also in sediments piled to thicknesses of thousands of feet on subsided lands that it is not. We may recur to the fact of the eighteen thousand foot uplift of Tibet during the latest geologic epochs as proof of local increase of the earth's radius; an increase which on the evidence of gravity measurements is not due to added mass and must be attributed to augmented volume, that is to expansion; as of rising dough. William Bowie, the isostasist, cogently called the attention of geologists to the importance of changes of level attributable to changes of volume.

The causes of volume change beneath the crust are obscure, because we cannot measure the conditions or observe the effects in the laboratory of the earth. It is not merely that we cannot dig to such depths; the changes are so infinitely slow; a million years or ten millions being required for any marked change. But recent advances in geologic knowledge furnish some significant points regarding the processes at work beneath our feet.

It is established that the outer crust of the earth is a mosaic of relatively small erupted bodies; chiefly basaltic, partly granitic, which have been extruded in a molten condition at various times during the past two billion years and down to times so recent that the latest masses are probably still molten a few miles below the crystallized crust. Also it is known that these small molten bodies have been extruded from a solid shell 1800 miles thick, in which they presumably develop by melting, in consequence of the local generation of heat by disintegration of radioactive minerals. In the process of melting such a body expands and also generates gases, such as escape from volcanoes. The direction of least resistance is upward and the volume change must express itself by raising the overlying crust; as in simmering mush. The rate of heating is excessively slow; that of cooling by escape of gases and eventually by outflow of lavas becomes relatively more rapid, but is still geologically slow. The heating should result in uplift, the cooling in subsidence of local areas of the crust, a hundred to several hundred miles in diameter over the subterranean bodies.

Prof. Douglas Campbell of Stanford has recently called attention

to the remarkable likenesses that are found in the floras of Hawaii, the islands of Oceanica, Australia, and South America. He proves beyond question that there have been land connections between these now widely separated districts. At one time I would have sought to trace the connections as mountain ranges, as I did when coöperating with Charles Schuchert on the similar problem of identity of terrestrial organisms in Africa and South America in Permian time. The concept of isthmian links appeared sound, biologically, dynamically, and climatologically, as tested by the geographical requirements of the case. It does not, however, fit the Pacific conditions, except perhaps to link the Antarctic continent with Australia and South America. The connections in Oceanica are too broad and too complex to be explained by mountain ridges. The alternative assumption of uplift, followed by subsidence of the ocean bed, of the emergence of lands which have now subsided beneath the waters is more reasonable. That it contradicts certain preconceptions of mine regarding the permanent levels of continents and ocean beds does not affect the evidence. In the Philippines the Manila basin is a subsiding area. It is surrounded by volcanoes from which lavas are erupted and gases are constantly escaping. I attribute the subsidence to these conditions in a cooling mass a hundred miles in diameter. Closely adjacent lies the similar area of the Sibuyan sea, where raised coral reefs demonstrate active uplift. I consider the uplift to be due to increase of volume of a subjacent body in which the temperature is rising. Similar conditions on a larger or smaller scale are widespread throughout the southwestern Pacific. To them I would attribute the former expanse of land which once bore the now dispersed floras and also its disappearance beneath the waters. The average depth of the Pacific, 4,000 to 5,000 meters, is not excessive in comparison with known uplifts and subsidences in continental areas. BAILEY WILLIS.

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DISCUSSION.

FURTHER DISCUSSION OF CONTINENTAL DRIFT.

I may say—in a modification of Professor Willis' own phraseology—that I should like to join him in believing the vexed question of continental drift can be settled now, once for all. In my view, however, the issue is not as simple as he represents it. No better test than the one he proposes could be chosen to illustrate the difficulty of passing summary judgment. The principle of mechanics that demands suction in the rear of a floating object applies if the object is driven by an independent force *through* the medium; the principle has no relation to objects that float passively on a broad current in the medium itself. Thus the test suggests an objection to the particular mechanism proposed by Wegener, a mechanism which in any case fails much more convincingly under quantitative evaluation of the forces he invoked (Jeffreys, 1929). The test has no validity, however, in an appraisal of convection currents as a possible mechanism of continental displacement (Holmes, 1933)—a suggestion that has received serious consideration from competent geophysicists. This hypothesis of convection currents may be attacked in its turn, by use of tests other than the suction principle. However, even if convection could be ruled out, other suggested answers would confront the test which Professor Willis views as conclusive. For example, some proponents of the drift hypothesis hold that the striking resemblance of opposed shorelines in South America and Africa is purely coincidental; that actual edges of the displaced blocks, concealed by the Atlantic on the continental shelves, show no such close similarity. These proponents would say that fragments probably were detached, and that they now form the shoaler parts of the South Atlantic floor; it is not a necessary assumption that such fragments would now stand above sealevel as islands—and there are at least the Falklands. We may therefore continue Professor Willis' analogy of fairyland by commenting that he has struck off the head of a monster, only to reveal it as a Hydra which still has several vigorous heads to spare.

In somewhat more serious vein, we may liken the problem of diastrophism to a mathematical equation in which essential terms are missing on both sides. On the right side of the equation we set down known effects as revealed in rock deformation and crustal movements. Any such statement is incomplete; for example, we lack important information on the depth to which deformation extends, and on the amount and the nature of horizontal shift of crustal blocks. We are especially in ignorance, however, about the left side of the equation, in which should appear the causes of diastrophism. It would be gratifying to know the important items

that certainly belong in that part of the equation, even if coefficients, exponents, and signs required for a quantitative expression remained lacking. Actually, we are still groping for even a qualitative expression that satisfies. If heat is the ultimate source of the required energy, by what means is it converted into work? Does gravity play a part, and if so by what mechanism? Bold spirits among us assume terms and values, but no convincing results have been offered thus far. Some of the assumptions appear irrational to many of us, but who can presume to set the exact limits of rationality? Any present approach to the problem must involve large-scale speculation, and even "outrageous" hypotheses should receive consideration, since the true solution, if it could become suddenly available, might well outrage some of our preconceptions.

Therefore I am not ready to brand as a fairytale the entire concept of displaced continents, although some published versions of the supposed evidence and mechanism must take higher rank as imaginative writings than as scientific treatises. Several conspicuous weaknesses characterize leading contributions of protagonists. There is a tendency to make extravagant claims by representing evidence as *compelling* when it is at best only *suggestive*; facts unfavorable to the hypothesis are ignored or dismissed lightly; data from one part of the world are seized upon as significant without consideration of the world-wide implications; vague suggestions that could be analyzed and in some cases eliminated by the authors are left in an undigested state to confuse and even mislead readers. Some examples of these defects were mentioned in my earlier discussion (Amer. Jour. Sci., April, 1944). Problems of plant-distribution in the Pacific basin, discussed in that article and now cited by Professor Willis also, cannot be solved by any scheme of continental drift thus far offered, although similar problems elsewhere are listed among the chief arguments for the drift hypothesis.

It is not difficult to refute some of the arguments offered for continental drift, and to show that even the best arguments are inconclusive. However, the goal of scientific endeavor is to learn the truths of Nature and not to win debates. Until we can establish an explanation of diastrophism that excludes the possibility of migrant continents, the hypothesis will have value at least as a stimulant, and as a constant reminder of the long road ahead in pursuit of this fundamental geologic secret.

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SCIENTIFIC INTELLIGENCE

CHEMISTRY.

Electronic Interpretations of Organic Chemistry; by A. EDWARD REMICK. Pp. v, 474, New York and London, 1948 (John Wiley & Sons, $4.50).—The book opens with a brief historical introduction to theories of chemical affinity, discussing first pre-electronic theories (Chapter I) and then the electronic theory and its early applications to problems of organic reactivity (Chapter II) and molecular structure (Chapter III). The Author then proceeds to gather together certain modern contributions from physical chemistry and to fuse them with the electronic theories of organic chemistry, obtaining in the process a set of "basic principles." These are designed to help the organic chemist to understand and predict the effects of structural and environmental changes upon the courses and mechanisms of reactions. In Chapter V the electronic theory of the English school is reviewed in a most clear and illuminating manner. This is then amplified and interpreted in the light of the resonance concept and of other contributions from chemical physics (Chapter VI). In Chapter VII the development of kinetic theories is reviewed, and the modern viewpoint is used in examining and clarifying some of the basic principles of the electronic theory. Oxidation-reduction reactions are dealt with in Chapters IV and VIII. Electron-pairing reactions in which each reactant contributes one electron to the new bond, and electron-sharing reactions, in which one reactant (ionic or not) shares a pair of electrons with another, are discussed in Chapters IX and XI. The rôle of the solvent in influencing reactions, and in relation to electronic theories is surveyed in Chapter X, one of the most interesting in the book.

An interesting and most useful feature of the book is the collection of six chapters in an Appendix. These chapters give a clear, modern exposition of such fundamental subjects as the theory of atomic and molecular structure (I), refractivity and chemical constitution (II), dipole moments (III), and background for the study of nonaqueous solutions (IV). The "basic principles" derived during the course of the text are gathered together for ready reference in V and a table of the symbols used in the text is given in VI.

This book should find a place in the personal libraries of most organic chemists. Professor Remick has not only gathered together a great deal of related and useful material and reduced it to reasonable order but he sets it down clearly and in a manner which makes his book a pleasure to read. In his Preface the Author says

"It is intended that this book shall serve the dual purpose of a review and an advanced text-book." In the opinion of this Reviewer he has admirably succeeded in this intention.

The book is remarkably free from misprints and the type is clear.

HAROLD G. CASSIDY.

Emulsion Technology, Theoretical and Applied; by W. R. ATKIN, et al. editors. Pp. xi, 290; a few figures. Brooklyn, N. Y., 1948 (The Chemical Publishing Co., $5.00).—This book is a collection of papers presented at a symposium of the British Section of the International Society of Leather Trades' Chemists with some additions by American authorities. It is a very practical book and includes formulations, manufacturing methods, machinery for and properties of various industrial emulsions.

Agricultural sprays, food emulsions, paints, rubber latex, asphaltic emulsions, and those used in the wool textile and leather trades are considered in some detail. The book should be of considerable value to those undertaking a new venture in this field, but it is of less interest to those concerned with theoretical considerations.

HARDING BLISS.

GEOLOGY.

Geological expedition of the University of Amsterdam to the Lesser Sunda Islands under the leadership of Professor H. A. Brouwer. Vol. 1, pp. 348, 5 maps, 68 text figs., 20 pls. New York, 1940 (Nordeman Publishing Co., $8.40).—In spite of extensive publications on the Permian and Triassic faunas of Timor, the geology of this outermost island of the Sunda group is still but little known. The amazingly rich Permian faunas previously described in *Paleontologie von Timor* and in the reports of the *Second Netherlands Timor Expedition* were collected from small disconnected outcrops of beds that are highly deformed and now poorly exposed. As a result, the stratigraphy has never been worked out and no geologic map of the island is available.

Professor Brouwer's expedition of 1937 with a group of students has made a most welcome beginning toward a detailed study of this fascinating island. The present volume includes four distinct papers two of which are devoted to the geology and two to paleontology.

The first part, by D. Tappenbeck, describes the structure and stratigraphy of the Mollo Range and adjacent country in the heart of the western (or Netherland) half of the island, and is written in German. The second part, by A. L. Simons, discusses the geology of an area in the extreme northeast corner of Netherland Timor, and is written in English. Part three, by J. Wanner, is devoted to

the blastoids which constitute such a surprising and distinctive element in the Permian faunas of Timor. Beside describing several new species and two new genera, Doctor Wanner proposes a new systematic arrangement for the blastoids of the world, and sets up five new families. The fourth part, by F. A. H. W. deMarez Oyens, is devoted to the Permian crinoids from the region about Basleo, describing two new genera and thirteen new species and redescribing many others. Both paleontological papers are written in German and their illustrations are excellent.

Doctor Tappenbeck shows that the major structure of the island is geanticlinal and has resulted from a long series of crustal deformations ranging from Paleozoic to mid-Cenozoic dates. The highest part of the ranges that form the longitudinal axis of Timor consists of a core of crystalline schists presumably of Paleozoic age but obviously older than the richy fossiliferous Permian rocks of the island. The flanks of the Mollo Range are formed largely of Mesozoic beds in two series, the older largely Triassic (but including Permian) and the younger largely Cretaceous. The structure is complicated by strong folding as well as faulting, and the stratigraphy is further complicated by local differences of facies ranging from immense limestone reefs to fine grained and supposed bathyal clays. Volcanic rocks are also associated with Permian and Triassic strata as well as with Cenozoic beds.

Descriptions and detailed maps by Simons of the northeastern part of Netherlands Timor and by Oyens of the region about Basleo, emphasize the complexity. Outcrops are found chiefly along the streams and are relatively small and discontinuous so that the stratigraphic relations of one to the next commonly cannot be determined. This will explain the fact, so distressing to students of the Permian faunas, that the several paleontologic monographs on the fossils of Timor give almost no stratigraphic data and no basis for an analysis of the association of different groups of fossils such as fusulines, ammonites, blastoids, and crinoids. It is still impossible to check the stratigraphic implications of one group of fossils against another, and even the succession of the four series of the Permian rocks of Timor, now so widely recognized, rests entirely upon a faunal rather than a stratigraphic basis.

Usefulness of the present volume would have been increased by a key map showing the relation of the several regions here treated in detail to the island as a whole. For American geologists there is still urgent need of a large scale geographic map of Timor showing place names that are used in the extensive paleontological literature. CARL O. DUNBAR.

The Cretaceous Rocks of South India; by L. RAMA RAO. Lucknow University Studies, No. XVII. Pp. iv, 78, 4 text figs., 1942.—

This small volume contains the substance of two lectures delivered by Doctor Rao at the University of Lucknow in 1941. It gives a clear, summary account of the Cretaceous rocks that crop out in the coastal belt along the southern half of the east coast of India.

The Cretaceous rocks of this region are divided into four groups and range in age from Cenomanian to Danian, thus representing much of the Upper Cretaceous system. They are chiefly sublittoral, very shallow water deposits, including conglomerates at several horizons. There is a zone of coral reefs near the base and another higher in the system. Locally there are deposits of gypsum and selenite and of phosphatic nodules. Next to the uppermost group may be non-marine for, instead of marine fossils, it has recently yielded a variety of dinosaur remains including sauropods.

CARL O. DUNBAR.

Plant Geography.

Foundations of Plant Geography; by Stanley A. Cain. Pp. xiv, 556; 68 text figs. New York and London, 1944 (Harper and Brothers, $5.00).

An Introduction to Historical Plant Geography; by E. V. Wulff, translated by Elisabeth Brissenden. Pp. xi, 223; 85 text figs. Waltham, Massachusetts, 1943 (Chronica Botanica Co., $4.75).—A study of plant distribution has two aspects, one descriptive and analytical, the other philosophical and interpretive. *Descriptive* plant geography attempts to record the distribution of plant species and analyze plant associations in communities of greater and lesser ranks; *interpretive* plant geography seeks to explain this distribution.

Doctor Cain points out that many different fields of science may contribute to such interpretation and he attempts to review and synthesize all the principles that can be deduced from these borderline fields. His volume thus constitutes "an inquiry into the foundations of plant geography." In addition to plant morphology and physiology, he finds that such widely different disciplines as cytology, ecology, genetics, systematics, climatology, geology, and paleontology are all involved, and he has undertaken "to cut the hedgerows between these fields of science, and to discover, * * * some of the significance which one field has for another."

The introduction to Doctor Cain's work discusses the borderline relations of plant geography, and marshals, in outline form, the chief principles used in the interpretation of the phenomena of plant distribution, following this by a brief discussion of each in turn. Succeeding chapters treat in more detail some of the principles that have thus been set in perspective in the introduction.

This volume is not intended for elmentary students or the layman—the discussion maintains a high level of abstraction and

involves the highly technical jargon of several specialized disciplines—but advanced students and professional botanists, as well as specialists in borderline fields, will find it indispensable as the only comprehensive synthesis of this kind, and they will be grateful that, notwithstanding its highly technical character, Doctor Cain has organized and presented it so clearly and effectively. The preface and uncommonly gracious acknowledgments suggest what delightful reading the author could make of less technical subject matter.

Doctor Wulff, a distinguished Russian paleobotanist, worked from a somewhat different viewpoint and did not so sharply separate the descriptive from the interpretive aspects of plant geography. In his words, "Historical plant geography has as its aim the study of the distribution of species of plants now existing and, on the basis of their present and past areas, the elucidation of the origin and history of development of floras, which, in turn, gives us a key to an understanding of the earth's history."

Doctor Wulff recognizes the interrelation of plant geography and other disciplines such as paleobotany, taxonomy, paleogeography, paleoclimatology, and historical geology, and discusses these relations briefly in Chapter I. In Chapter II he gives a historical review of the growth of the science of plant geography. Chapter III is devoted to a description and analysis of *areas*; Chapter IV discusses the origin of *areas*; and Chapter V analyzes different types of *areas*. Chapter VI treats of parallelism in the geographical distribution of plants and animals and correlation between the distribution of parasites and that of their plant hosts. The influence of man on plant distribution is discussed in Chapter VII, and Chapter VIII is concerned with natural means of plant dispersal such as winds and water currents. Migrations are discusssed in Chapter IX. Having shown that in many instances present distribution cannot be accounted for on the basis of existing factors, he shows in Chapter X the importance of inheritances from other distributions in the geologic past. The final chapter is devoted to the concept of *floral elements*.

CARL O. DUNBAR.

American Journal of Science

OCTOBER 1944

LITHOLOGY OF THE KENNEBEC VALLEY ESKER.

JOSEPH M. TREFETHEN AND
HELEN B. TREFETHEN.

ABSTRACT. An investigation of the lithology of the Kennebec Valley Esker, Maine, shows that the bulk of the material, both fine and coarse fragments, is dominantly of local origin.

INTRODUCTION.

ONE of the problems of eskers is the origin of the component rock fragments. Among the questions raised are these: Is esker material chiefly of local origin or has it been carried considerable distances? What are the relative proportions of immediately local rock types and more distantly derived fragments? How far is the bulk of the material transported? In attempt to answer these questions a study was made of one particular Maine esker system. Effort was also made to determine the difference in amount of transportation of the fine and the coarse fractions.

THE KENNEBEC VALLEY ESKER.

The esker chosen for this investigation is shown on the map (Fig. 1). It begins in Hartland township and extends southerly at least as far as the town of Dresden, a distance of about fifty miles. The esker ridge is not continuous throughout this distance, but, as shown on the map, consists of a series of ridges. From Fairfield to the south the segments are shorter, and the continuity of the esker more broken. The average relief of the esker is from twenty to forty feet. Locally, however, relief amounts to more than seventy feet.

LITHOLOGY.

Country Rock. The esker rests on granite at its northern end. South of the granite it lies on a quartzite and schist

area, the northern part of which, adjacent to the granite, contains numerous patches of granite intrusion. This formation becomes shaly toward the south. South of this transition zone, the esker extends over an area underlain by the Waterville shale, which has interbedded quartzite and minor limestone layers. South of Waterville it crosses interbedded shaly slates and schists. Just north of Augusta it enters a terrain underlain by schists and interbanded gneisses. South of Augusta it passes between the granite hills of the Hallowell batholith and continues to the south over schists and gneisses which are increasingly injected by granites and pegmatite in that direction. The relations of the esker to the underlying bedrock are shown in Fig. 1.

Gravel and Sand. Pebble counts were taken in gravel pits at intervals of two to four miles along the course of the esker. The counts consisted of two hundred pebbles picked up at random in each pit. The size of the pebbles varied from one-half inch to three inches in diameter.

Sand samples were also obtained and counts made in the sand and granule sizes. Each sand sample was put through a set of screens of sizes 8, 14 and 28 mesh to the inch. One hundred grains of the material retained on each, taken at random, were classified. From the finer sizes little information as to origin was obtained. In the northernmost counts, where the esker lies near the granite batholith, granite constitutes about 80 per cent of the count, both large and small sizes. Approximately eight miles south of the main granite mass, the granite count is decreased to 10 per cent for fine sizes, while in the larger sizes granite is fairly high, 20 per cent. An average of about 6 per cent granite persists in the counts throughout the schist and shale area. It is not certain how much of this is far transported and how much comes from small intrusions which occur throughout this section.

The shale enters the samples to a marked degree within five miles of the area where it constitutes a considerable quantity of the country rock. In the center of the shale and quartzite area, shale constitutes about 20 per cent with the local quartzite averaging about 60 per cent in the pebble counts. In the finer sizes, shale and quartzite are about 40 per cent and 50 per cent respectively. This change in proportions is natural as the shale, weaker than the quartzite, was more susceptible to glacial grinding. In the area of schists and slaty shales

south of Waterville, schist constitutes about 40 per cent and shale 34 per cent for the smaller sizes. Here the schist is the softer rock. The larger sizes show 35 per cent shale and 15 per cent schist. The count for rotten rock was unusually high, about 20 per cent. Most of the pebbles classified as rotten rock were schist.

The schist count increases to the south as the schist area near Augusta is reached. In the large sizes, shale particles decreased to about 5 per cent, with an increase to 40 per cent schist and 8 per cent rotten schist. In the same count, the fine sizes show 30 per cent shale, but in Augusta this high percentage falls off to no shale in the pebble size and to only about 6 per cent in the small size.

There is a rapid and large increase of granite almost as soon as the esker enters the Hallowell granite area, so that inside of six miles it has increased from 6 per cent to 35 per cent in the smaller sizes and a corresponding increase for the large sizes. Within the area, the granite content increases to 46 per cent with the surrounding schist constituting 43 per cent. From here on mica gneiss, the principal country rock, makes up an average of 85 per cent of the samples in all sizes. Some schist is present also, but this decreases markedly four miles south of the principal schist zone.

In addition to the studies of materials just discussed, heavy mineral separations were made from the sands in an attempt to get an estimate of the extent of transportation of the fine material. Twenty gram portions of each sand sample, screened through the 60 mesh screen, were run through acetylene tetrabromide to recover the heavy minerals. In addition, samples of the different types of country rock crossed by the esker were crushed and run through the heavy liquid in order to compare the heavy minerals of the esker sands with those of the adjacent country rock.

The Heavy Minerals. The study of the heavy minerals gave no positive information as to the length of transportation. Throughout the course of the esker from which samples were taken, the sand contains a large amount of heavy minerals. The principal minerals are garnet, magnetite, hornblende and tourmaline, with lesser amounts of pyrite, ilmenite, zircon, apatite and augite. The same general mineral assemblage persists through all the samples. Pyrite is present in only a few cases where the sample was taken from near pyritiferous schists

and shales. This mineral, however, was not carried far beyond the source.

In general, the minerals are those found in granites, gneisses and schists, and come from fragments of these rocks present in the sand and gravel. The shales are very poor in heavy minerals with nothing diagnostic except possibly the pyrite. Furthermore, the heavy minerals of the granite and schist of the northern area are similar to those in the southern section. It may be that these intrusions are genetically related, a possibility hitherto not given consideration. For these reasons it cannot be definitely stated that the heavy minerals are transported from one end of the esker system to the other. The percentage of heavy minerals in the sand shows an incrase when it enters the southern granite-gneiss area after passing through the shale and quartzite. Here again the influence of local material is marked. The decrease in the percentage of heavy minerals before reaching the southern granite area is due to the decrease of material derived from the crystalline rocks in the sand and gravel.

The heavy minerals show some degree of rounding, but not enough to indicate extensive transportation. Subangular fragments dominate, numerous angular fragments are present, well rounded grains are rare.

In order to get more definite information as to the extent of transportation of the heavy minerals, it would be necessary to take samples from an esker which crossed rocks with different heavy mineral assemblages in each. At the outset of this investigation it was believed that this might be the case for the Kennebec Valley esker.

DISCUSSION.

Due to the similarity of some of the formations in this part of the State, it is difficult to tell how far many of the pebbles have been carried. It seems safe to say, however, that not over 5 per cent, and in some of the counts less, is of more distant origin than 50 miles. Obviously the character of the rock is a factor in the distance of transportation. In general, the majority of the minerals has been transported for distances of three to eight miles, hence is principally of local origin.

The larger sizes of the material tend to break as they are carried. Fragmentation thus increases the proportion of sand sizes of a lithologic type near the contacts. Because of vary-

ing stream competency the larger sizes tended to drop out earlier than the small. Thus the finer sizes have a wider range of distribution than the larger.

The results of this investigation are in essential agreement with earlier studies on the transportation of esker materials, both in the United States and Finland. For purposes of comparison with these present findings, some results of earlier researches along similar lines are of interest.

Davis (1892, pp. 477-499) found that the material in the Newton-Auburndale esker in Massachusetts was derived from two to four miles of its present location.

Stone (1899, p. 432) observed that material enters the composition of esker within less than a mile of the outcrop. He also noted that in some large eskers, as the Katahdin esker, material seemed to be transported farther than in smaller eskers.

Alden (1918, p. 287) in his work on the Wisconsin eskers determined that 91.5 per cent was derived from the local rock and 8.5 per cent was foreign.

Aaro Hellaakoski (1930, pp. 1-41) made a study of the transportation of materials in the esker of Laitila, located in southwest Finland. This was an excellent location for such a study because the esker crosses the Rapakivi granite for 27 km. with the older rocks on either side. He concluded that the majority of the esker material was transported five to eight km. (about three to five miles) from the source in the bed rock. The material from an outcrop appeared in the esker at about that distance from the contact, increases in amount, and then the decrease is rapid at the same distance on the other side of contact. He concluded, "The overwhelmingly greater part of the esker material is derived from nearby sources." His results indicate somewhat less transportation than those for the Kennebec Valley esker.

Reference to the map (Fig. 1) brings out another problem. It will be seen that the esker passes between the granite outcrops of the Hallowell batholith but, itself, rests on schists, which separate the granite exposures east of the Kennebec River, from those west of the river. How then does the granite from these lateral areas become so quickly incorporated into the stratified drift? Prest (1917-18, pp. 371-93) has suggested that eskers are a result of lateral movements of the ice towards the esker ridges. Marginal troughs have been cited

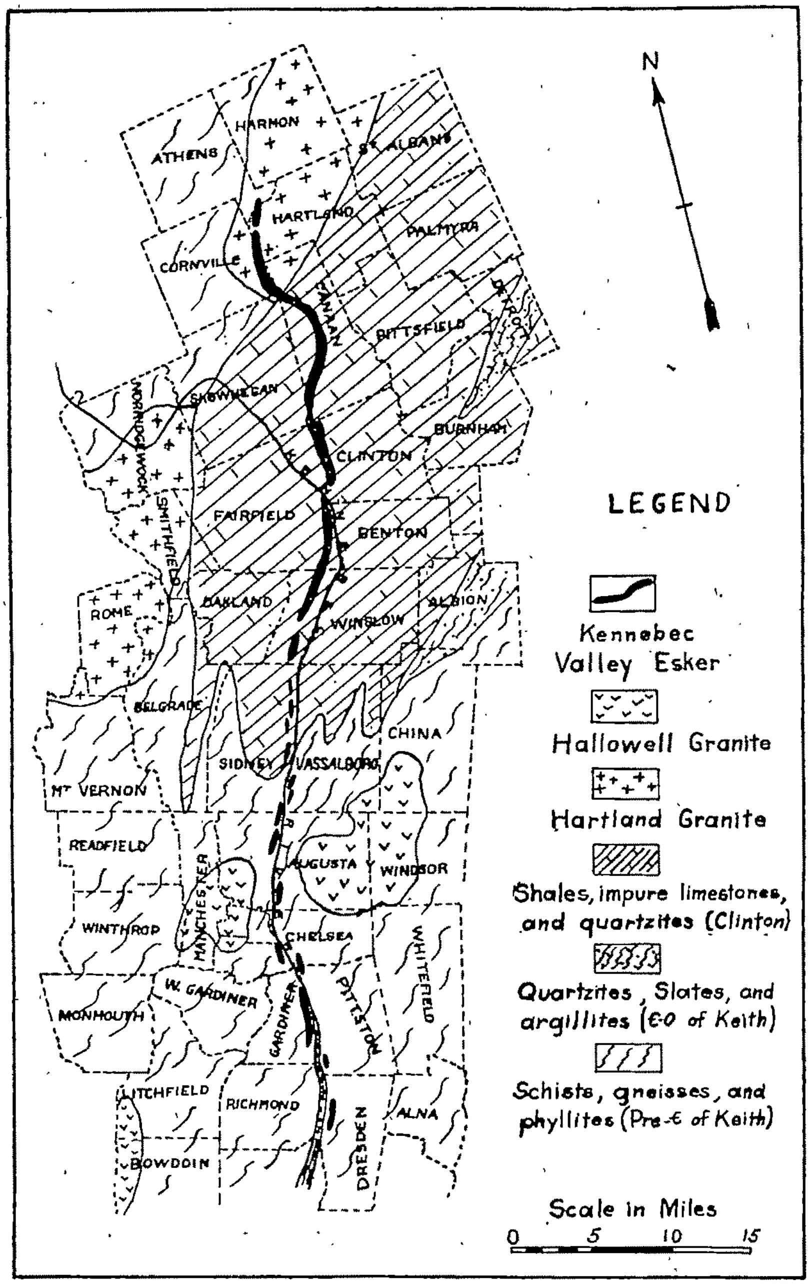

Fig. 1. The Kennebec Valley Esker in Relation to the Bed-rock. (After Preliminary Geologic Map of Maine, Ed. of 1933, Maine Geol. Survey, and Glacial Geology of Maine by E. H. Perkins.)

as evidence of such lateral shove. No striations indicating such movement have come to the writers' attention, and inasmuch as eskers are among the last deposits of glacial origin such striations should be found, locally, at least. If the ice sheet were essentially stagnant at the time of esker building, as seems reasonable, the above theory is inapplicable.

Another possibility, accounting for the transportation of materials from the lateral regions might be suggested. The principal stream is probably able to incise itself deeper in the ice than the minor streams tributary to it. Very possibly these were hanging tributaries in the ice. The competency of the tributaries, consequently, might be such as to transport most of the material, leaving little in the way of channel deposits to form branch eskers.

In conclusion it may be stated as the writers' conviction that further critical field work is essential to continuing the discussions of these problems: to quote from Tanner (1932, p. 13), ". . . only the systematic analytic investigation of representative instances according to the method of concomitant variations, can guide us to a true conception of the history of the formation of eskers."

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QUANTITATIVE DETERMINATIONS OF BORON IN SARATOGA MINERAL WATERS.*

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ABSTRACT. The results of quantitative determinations for the element boron in Saratoga Mineral Waters are presented for the first time. Additional precautionary measures used in the experimental procedures for determining this element are briefly discussed. The concentrations of several of the elements present in the mineral waters are tabulated and their ratios with each other and with boron are given.

THE presence of boron in the Saratoga mineral waters has been known for many years but up to the present time, no quantitative determinations have been recorded. In view of the great physiological interest in this element, quantitative determinations were made of the mineral waters as a preliminary phase to further work.

A study was made of the ratios of boron with respect to other elements present in the waters but no conclusions are given as there seems to be no simple correlation between the amounts of boron or ratios of other elements with boron. The concentrations and ratios are given here as a matter of interest.

EXPERIMENTAL.

As a result of much preliminary work, in which various methods, and variations of these methods, were used in determining boron in the mineral waters,[1-3] it was found that the method of Naftel[4] was suitable for the work here. In using this method, checks were made by running blanks and standards that were treated exactly the same as the samples. Blanks were used that simulated the mineral content of Hathorn 2 water. To these were added different amounts of boron and these were checked against standard solutions of H_3BO_3, and

* A second paper on boron is in preparation. The absorption of boron through the skin is its object. Boric acid is lipoid and water soluble. Boron possesses a remarkably strong affinity for forming cyclic complexes with OH groupings. Boron penetrates through the lipoid wall of living cells and enters through the skin into the bloodstream. O. Baudisch.

samples to which had been added the same amount of 0.1n $Ca(OH)_2$ suspension as was added to the blank. After evaporating and drying on a steam bath, the same amount of freshly made HCl-oxalic acid mixture and alcohol solution of turmeric were added to each. The drying took place in an electric oven at $55 \pm 3°$ for the same length of time for standards, blanks and samples of each run. The extraction was made with 95 per cent alcohol, centrifuged and a comparison of colors was made in a Klett Biocolorimeter.

It was found that differences in results obtained while using standard solutions of boric acid and blanks to which boric acid had been added were very slight. Therefore, for some of the runs, standard solutions of boric acid with no salts added other than calcium hydroxide were used as standards of comparison. In order to obtain more accurate results these standards were run with each series of samples, treated the same and for the same lengths of time, and contained approximately the same amount of boron as the samples. As the red color formed is unstable, comparisons were made as soon after formation of color and extraction as was possible. Sunlight was excluded and 95 per cent alcohol was used as the color change is more rapid in sunlight and when water is present in the solvent.

The blanks, which were made to simulate Hathorn 2 water were prepared as follows: 0.06 g ammonium chloride, 8.5 g sodium chloride, 0.1 g potassium bromide, 0.4 g sodium bicarbonate, 2 g calcium carbonate, 1 g magnesium carbonate. Made up to a volume of one liter with distilled water. Samples of this solution were treated and no red color was developed. When known amounts of boric acid were added to samples of this solution and compared with standard solutions of boric acid treated the same way, the recovery was such that it was not considered necessary to run blanks containing these salts. Comparisons between blanks and samples, and standards and samples gave similar results.

In the treatment of mineral water samples it was found that it was only necessary to add enough calcium hydroxide to make the sample alkaline and then to evaporate and dry on a steam bath and follow the usual procedure.

The results shown in Table One give the upper and lower ranges and averages of from seven to twelve samples of each water. At least three samples were taken for each run and these were taken on different dates. Samples and standards

were of such size as to contain 5 to 50 gammas of boron. Better results were obtained with the smaller samples.

Checks were made on some of the waters that had been standing open to air and protected from contamination for periods

TABLE 1.

Spring	Boron-Range Mg/L	Average Mg/L
Hathorn 2	5.3 –5.8	5.5
Hathorn 3	3.1 –3.3	3.2
Orenda	1.7 –2.1	1.8
Hayes	1.9 –2.2	2.0
Coesa	3.2 –3.3	3.3
Hathorn 1	2.0 –2.3	2.1
Lincoln	2.1 –2.6	2.4
Geyser	2.2 –2.4	2.3
Red	0.37–0.50	0.46
Sea Water	4.5 –5.0	4.5–5.0

of from four days to three weeks. There was no change in the boron content of the supernatant liquid. This showed that the boron did not precipitate out and that there was no change in results even though the iron and considerable calcium and magnesium salts had precipitated out.

DISCUSSION.

No deductions have been made as to the sources of boron or of the concentration or ratio with other elements. Some interesting comparisons and ratios are given of concentrations of some of the elements in the waters. As can be seen in Table 2, there is a direct relation between total solids and chlorides. With an increase in solids there is an increase in percentage of chlorine to total solids and a decrease in per cent of bicarbonates. With few exceptions there is a direct relation between total solids and calcium, magnesium, potassium and the bicarbonate radical. (Tables 2 and 3).

However, of the other elements, some of which are listed here, there seems to be no correlation as to concentrations or ratios although the ratio of I : B, HCO_3 : B, and K : B are quite similar in some cases.[5-6]

In only one water, Hathorn 2, is the concentration of boron greater than that of the average lithosphere, (3.3 Mg/Kg).[7]

TABLE 2.

Spring	Total Solids	Chlorine as Chlorides	Br	I	Boron	Ratios: Total Solids : Cl	Total Solids : B	Cl : B	Br : B	I : B
Hathorn 2	14,581	5,099	30.8	2.7	5.50	2.86:1	2,651:1	927:1	5.6:1	.49:1
Hathorn 3	14,186	4,979	65.5	2.39	3.19	2.85:1	4,447:1	1,560:1	20.53:1	.90:1
Orenda	11,994	4,011	1.07	.92	1.83	2.99:1	6,554:1	2,192:1	.584:1	.50:1
Hayes	11,742	3,870	20.1	.95	2.02	3.03:1	5,812:1	1,916:1	9.95:1	.47:1
Coesa	10,180	2,967	9.4	1.04	3.29	3.41:1	3,079:1	902:1	2.86:1	.32:1
Hathorn 1	8,455	2,418	8.95	.87	2.1	3.5:1	4,026:1	1,151:1	4.26:1	.41:1
Lincoln	8,296	2,085	10.02	1.06	2.35	3.98:1	3,530:1	887:1	4.26:1	.45:1
Geyser	7,284	1,441	6.2	.84	2.33	5.05:1	3,126:1	618:1	2.66:1	.36:1
Red	2,874	574	4.0	.3	.46	5.00:1	6,194:1	1,287:1	8.62:1	.65:1
Sea	35,000	19,341	66.0	.05	4.5–5	1.81:1	7,000:1	4,298:1	14.66:1	.011:1

Concentrations in Mg per Liter

TABLE 3.

Spring	Concentration					Ratios					
	Ca	Mg	K	HCO_3	Li	Ca:B	Mg:B	K:B	Total Solids:HCO_3	HCO_3:B	Li:B
Hathorn 2 ...	799	331	468	4,602	7.2	145:1	60:1	85:1	3.17:1	837:1	1.31:1
Hathorn 3 ...	786	319	481	4,415	12.5	246:1	100:1	135:1	3.21:1	1,380:1	3.92:1
Orenda	739	273	*238	4,087	6.1	404:1	149:1	130:1	2.93:1	2,230:1	3.33:1
Hayes	705	270	*254	4,040	3.97	349:1	134:1	126:1	2.91:1	2,000:1	1.97:1
Coesa	628	197	380	3,868	7.6	190:1	60:1	115:1	2.62:1	1,175:1	2.31:1
Hathorn 1	537	194	234	3,321	3.55	256:1	92:1	111:1	2.55:1	1,580:1	1.69:1
Lincoln	499	*210	201	*3,614	4.02	212:1*	89:1	86:1	2.29:1	1,540:1	1.71:1
Geyser	452	122	193	3,613	3.45	194:1	52:1	83:1	2.01:1	1,550:1	1.48:1
Red	250	74	65	1,419	1.30	539:1	160:1	140:1	2.02:1	3,060:1	3.09:1

* Apparent exceptions to direct relation with Total Solids.

TABLE 4.

Spring	Ra*(5)	Ba	Fe	Ratios Ra:B(5)	Ba:B	Fe:B
Hathorn 2	5.16×10^{-7}	28.0	5.9	$.938\times10^{-7}$:1	5.09:1	1.07:1
Hathorn 3		18.83	3.92		5.90:1	1.23:1
Orenda	1.24×10^{-7}	8.89	5.88	$.68\times10^{-7}$:1	4.86:1	3.21:1
Hayes		16.34	3.4		8.09:1	1.68:1
Coesa	1.99×10^{-7}	13.24	1.84	$.603\times10^{-7}$:1	4.02:1	0.56:1
Hathorn 1	2.84×10^{-7}	19.70	5.92	1.35×10^{-7}:1	9.38:1	2.82:1
Lincoln		7.8	24.50		3.32:1	10.42:1
Geyser	$.363\times10^{-7}$	8.83	3.12	$.158\times10^{-7}$:1	3.79:1	1.34:1
Red	$.25\times10^{-7}$	2.70	8.80	$.54\times10^{-7}$:1	5.81:1	18.97:1

Enrichment with respect to Fe. 900 (in Red) to 30,350 (in Coesa),
Ratio of Fe.B in Lithosphere=17,000:1 (7).
Ratio of Fe:B in Hayes water=1.68:1 (An average water).
Enrichment with respect to Fe=10,000.

However, in comparing the enrichment with respect to iron[6] in an average water (Hayes) the boron is enriched by a factor of 10,100 over the lithosphere.

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THE PHYSIOGRAPHIC FEATURES OF AN AREA IN EASTERN OHIO.

KARL VER STEEG.

ABSTRACT. Three major pre-glacial watersheds are present in eastern Ohio. Their presence indicates that in Tertiary time, the plateau section of Ohio was subdivided into four main drainage basins. The upland (Harrisburg) erosion surface is well preserved in the vicinity of Flushing and Bethesda, not far from the point where the major divides meet. Another surface, the Parker Strath, was developed at a lower level. The Worthington and Harrisburg erosion surfaces are in reality one continuous, rolling surface, higher on the divides and lower near the valleys. The writer believes the Worthington peneplane is non-existent and is a part of the upland (Harrisburg) surface.

Most of the tributaries flowing into the Ohio River exhibit entrenched meanders.

Many drainage patterns in eastern Ohio, having the trunk stream extending in an east-west direction, have longer tributaries on the north side than on the south. The asymmetrical pattern occurs to a greater or lesser degree over an area of more than 30,000 square miles and must therefore be the result of a general rather than a local cause. The streams inherited the pattern from the upland (Harrisburg) cycle of erosion. It does not appear probable that conditions during the ice-age had anything to do with the abnormal arrangement because it developed in Tertiary time. Furthermore, the tributaries in the glaciated portion of Ohio do not show the asymmetrical pattern.

THE area selected is located in the unglaciated portion of southeastern Ohio, in Columbiana, Carroll, Jefferson, Guernsey, Belmont and Monroe counties. The contrast in topography between the areas to the east and west of the Flushing divide, and the development of the asymmetrical arrangement of the tributaries of the streams which flow eastward into the Ohio River, make the region an interesting area for study. The evidence of the presence of an upland erosion surface (Harrisburg), is shown in this area better than at any other locality in Ohio.

PRE-GLACIAL DIVIDES IN SOUTHEASTERN OHIO.

Three major watersheds occur in eastern Ohio; the area under discussion is located near their intersection. One divide extends in an east-west direction and separates the south-flowing streams in southeastern Ohio from the north-flowing ones of the central and northern parts of the state. Another, running in a north-south direction separates the streams flow-

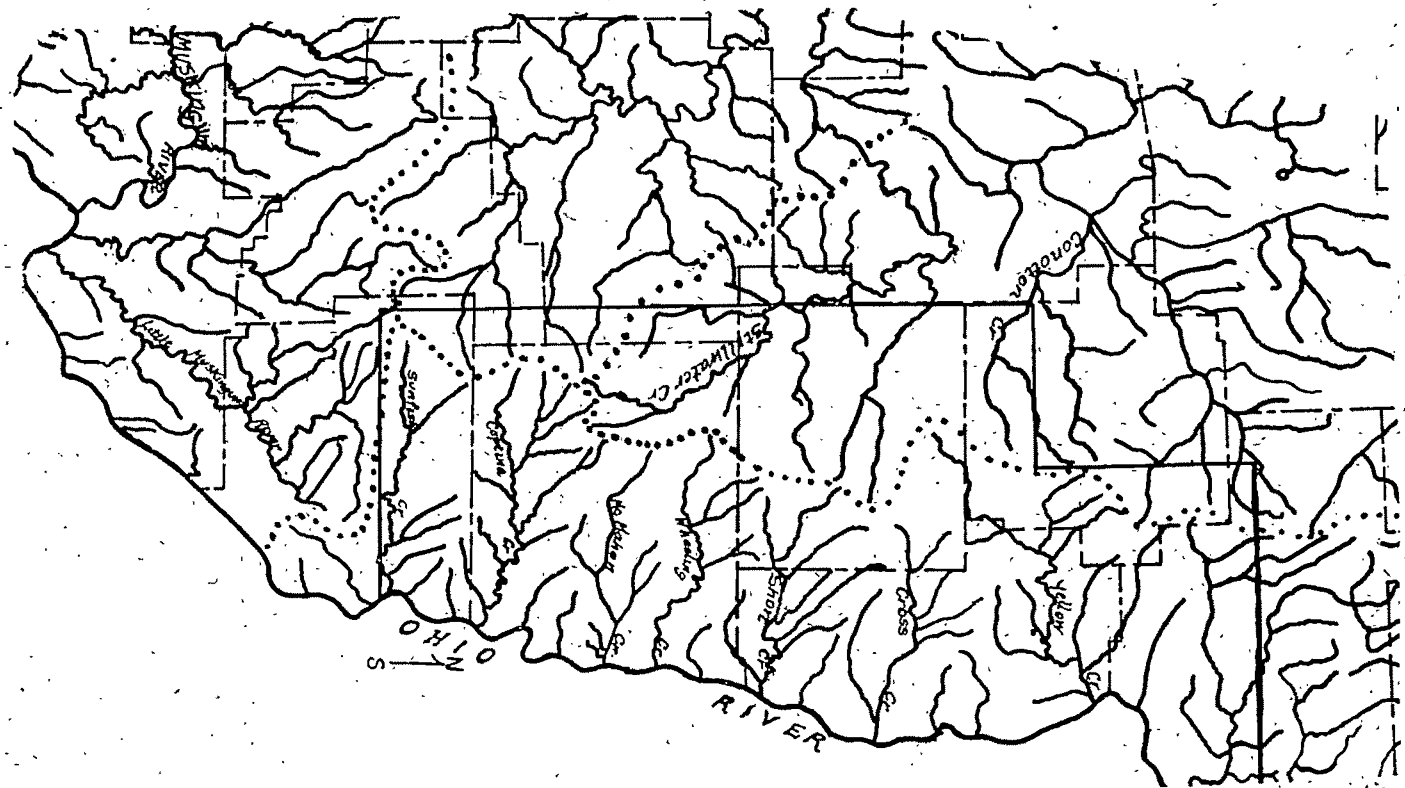

Fig. 1. Map of a part of Eastern Ohio, showing drainage lines. Area included within solid lines. Pre-glacial divides indicated by dotted lines. Scale 1 inch per 1,000,000 feet.

ing eastward into the Ohio River and those flowing northward. The third divide extends in a northwesterly direction from Belmont County, through Guernsey, Tuscarawas and Holmes counties and westward. The presence of the pre-glacial major divides indicates that in Tertiary time, the plateau section of Ohio was subdivided into four main drainage basins. These are the Erie, the southeastern Ohio (old Kanawha), the eastern Ohio (old Ohio), and the central Ohio (old Licking), drainage basins. The location of the pre-glacial divides makes easier the interpretation of drainage changes and the tracing of the old erosion surfaces. Since peneplanation is always more complete near the mouths of the streams and at points farthest from the divides, erosion surfaces such as straths become narrower headward, are poorly developed on the headwater divides and rise toward them, being broader and better developed along the lower courses of the larger streams.

DESCRIPTION OF THE UPLAND SURFACE.

The upland (Harrisburg) erosion surface, preserved on the hilltops and ridges was a surface of slight relief. The higher points on the divides stand from 1200 to 1400 feet, the greater portion lying between 1200-1300 feet. Along the creeks and Ohio River, the altitude ranges from 1100 to 1200 feet. Occasional monadnocks, represented by hills as high as 1447 feet, rise above the general level.

The upland surface, before uplift and dissection, was a gently rolling surface, sloping from the divides which stood, on the average, not much more than 100 feet above the stream valleys. The writer[1] believes that the so-called Worthington and Harrisburg surfaces are one and the same. There appears to be no conclusive evidence against such interpretation. The Worthington slopes from the spurs at the valleys, with no interruptions into the surface (Harrisburg) on the higher points. It is in reality only one continuous, rolling surface, higher on the divides and lower near the valleys.

The streams meandered broadly on the upland surface. This is indicated by the incised meanders exhibited by the Ohio River and its tributaries, Captina Creek, Yellow Creek, Little Beaver Creek, Sunfish Creek and Wheeling Creek; in fact nearly all the streams, even some of the smaller ones in the area, show

[1] Ver Steeg, Karl: 1940, Correlation of Appalachian Peneplanes. Pan-American Geologist, Vol. LXXIII. April, pp. 203-210.

entrenched meanders. This phenomenon is characteristic of many streams, large and small, throughout the Appalachians.

After the uplift, which ended the Harrisburg cycle of erosion, the streams in Ohio developed a surface which has been called the Parker Strath. This erosion level, according to Stout and Lamborn,[2] stands at approximately 960 feet in Columbiana County. The bench along the West Fork of Little Beaver Creek, near West Point, in the Wellsville quadrangle in Columbiana County, standing at 960-980 feet, may represent the Parker Strath. There are few places in the area at this level which can be interpreted as an erosion surface. The Parker Strath is well-developed farther west in Ohio, where it stands at about 800-900 feet, or about 200 feet below the Harrisburg surface. The absence of widespread remnants of the Parker Strath, in the area under discussion, and farther east in the Allegheny Plateau, can be explained by the fact that the streams farther west in Ohio were more advanced in the cycle and a strath was developed, whereas those farther east continued cutting downward. After the uplift of the Harrisburg surface, the streams in the area cut down 450-500 feet to produce the present strath along the Ohio River and its tributaries. Some of the latter have developed flood-plains up to their headwaters. The width of the valley floor of the Ohio River is about one-half to two-thirds of a mile and has an altitude of 700-720 feet in the northern part of the area and 620-700 feet in the southern portion. The Ohio River and its tributaries can be classified as in early maturity in the erosion cycle. After the uplift of the Harrisburg surface, the streams dissected the region into a topography which can be classified as early maturity. The region east of the Flushing divide does not appear to be as far advanced in the erosion cycle as the area drained by the westward flowing streams, Stillwater and Conotton creeks.

The fall in feet per mile, as calculated by the writer, appears to be greater for the streams flowing eastward from the Flushing divide. Wheeling Creek has an average gradient of about 19 to 20 feet per mile for its entire length. In the first mile and a half it drops 120 feet; in the last 7 miles its fall is greater than in its upper and middle course. Cross Creek has

[2] Stout and Lamborn: 1924, Bull. Ohio Geol. Survey, (4), No. 28, pp. 41-43.

about the same average gradient, about 20 feet per mile; this stream, like Wheeling Creek, has a fall in the last 9 miles as great as in its middle course. All the eastward flowing streams have about the same high, uniform gradient.

Stillwater Creek, flowing westward from the Flushing divide has an average gradient of 10 feet per mile, for the first 21 miles from the divide. Conotton Creek has an average fall of 13 feet per mile in a distance of 20 miles from the Flushing divide. From these figures, it is evident that the eastward-flowing streams have a much higher average gradient than those flowing westward from the Flushing divide.

The upland, shown on the Flushing and St. Clairsville quadrangles does not appear to be as thoroughly dissected as the region to the west, drained by Stillwater Creek and its tributaries, or the region along the Ohio River to the east. This is especially true of the uplands in the area about Flushing, Bethesda, Morristown, Belmont, St. Clairsville and New Athens. The headwater portions of the tributaries of the east-flowing streams, McMahon, Wheeling and Short creeks, appear to flow on the upland, in broader shallower valleys than is true of their lower courses nearer the Ohio River, where they have cut deep narrow gorges. The upland represents an older surface (Harrisburg), below which the streams on the east and west have entrenched themselves. The rejuvenated streams have not thoroughly dissected the divide in the vicinity of Flushing nor worked headward far enough to entrench themselves in the old valleys on the upland in that area. It appears that after the completion of the Harrisburg surface, the land was tilted as a result of uplift along the axis of the Appalachians to the east. Entrenchment of the streams below the Harrisburg surface followed. The streams thoroughly dissected the upland near their mouths, but on the major divides, remnants of it are still intact. Since the Flushing area is not far from the point where three major divides in Ohio converge, one would expect the preservation of the upland surface.

It is rather remarkable that there is so little evidence of stream piracy in the Allegheny Plateau region, in view of the great uplift that took place in post-Harrisburg time. This seems to indicate that the divides, established on the Harrisburg surface, did not shift much as a result of the uplift which followed the completion of that surface. If differential warping occurred in the widespread uplift of the Appalachian

Plateau, one would expect evidence of considerable piracy. In southeastern and eastern Ohio, where ice blockaded the streams

Fig. 2. Map showing portion of the Flushing quadrangle. Note the difference in topography east and west of Flushing divide.

south of the ice edge, disturbance of drainage occurred and in the area under discussion there are a few instances of stream piracy or drainage shifts, but none is the result of the headward encroachment of streams on divides between drainage basins.

ASYMMETRICAL ARRANGEMENT OF TRIBUTARIES.

G. F. Lamb[3] points out that many drainage patterns in eastern Ohio, having the trunk stream extending in an east-west direction, have longer tributaries on the north side than on the south. The length of the north side tributaries may average five times as great as those on the south. Lamb points out that the asymmetrical pattern occurs to a greater or lesser degree in the region beyond Ohio in West Virginia and Pennsylvania, over an area of more than 30,000 square miles and must therefore be more than a local occurrence and has a general cause.

The streams having the asymmetrical pattern drain areas of stratified rock of Paleozoic age. Lamb states that it is most strikingly developed where the rock is dominantly shale, as in the case of the Conomaugh and Dunkard series. Evidence is sufficient to indicate that the asymmetry is not the result of the primary stream shifting down-dip; that the dip of the beds has little or no effect on the length or course of the streams; that anticlines, synclines and fault lines apparently exercise no control.

The asymmetrical pattern is marked on the streams flowing into the Ohio River in Columbiana, Harrison, Jefferson, Belmont and Monroe counties. Cross Creek, Short Creek, Wheeling Creek, Sunfish Creek, and the Little Muskingum River show this phenomenon. Examples are shown on every quadrangle on both sides of the Ohio River, from East Liverpool to Wheeling. This stream pattern appears to be common only in the unglaciated region.

The problem as to the cause for the asymmetrical arrangement has not been solved. The writer believes that the streams inherited the pattern from the Harrisburg or upland cycle of erosion. The streams developed the pattern during the cycle which ended in the uplift of the Harrisburg surface. One might assume that complex warping accompanied the wide-

[3] Lamb, G. F.: Cause of Asymmetrical Drainage Pattern in Eastern Ohio, Ohio Jour. of Science, Report of 52nd Annual Meeting, Vol. XLII, July 1942, No. 4, p. 148.

spread uplift of the Harrisburg surface, giving the tributaries on the north the advantage. However, there does not appear to be sufficient evidence to indicate that complex warping occurred. The absence of widespread piracy opposes that theory. Structures in the overlying rocks, removed during the Harrisburg cycle, may have been a factor. Since the evi-

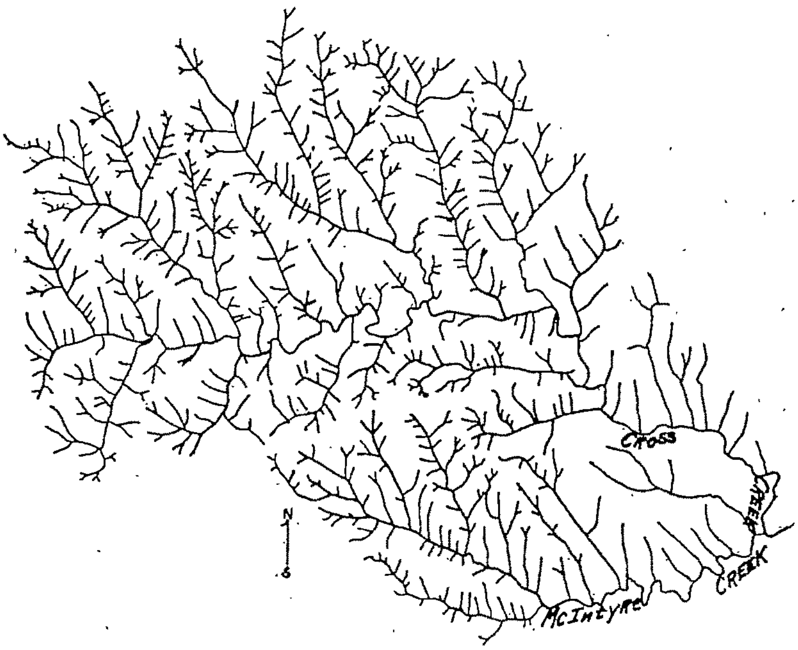

Fig. 8. Cross Creek, showing the asymmetrical arrangement of tributaries. Scale of map—1 inch equals 250,000 feet.

dence has been removed by erosion, one can only speculate as to the cause. Lamb[4] suggests that the amount of sunlight is a potent and probably the dominant factor. It does not appear probable that conditions during the ice-age had anything to do with the abnormal arrangement, because it developed before the ice-age in Tertiary time. Furthermore, the tributaries in the glaciated section of Ohio do not show the asymmetrical pattern.

[4] Idem, 8, p. 148.

WOOSTER, OHIO.

THE BINARY SYSTEM P_2O_5-$2CaO.P_2O_5$.

W. L. HILL, G. T. FAUST AND D. S. REYNOLDS.

PART II.

DESCRIPTION OF THE PHASES.

CHARGES containing more than about 22 per cent calcium oxide presented no difficulties in their optical study. The hygroscopic nature of charges containing less calcium oxide necessitated examination immediately after removal from the furnace. The formation of reaction rims on the glass fragments upon exposure to the atmosphere was avoided by crushing a portion of the charge covered with the proper immersion liquid in a mortar and then transferring the mixture to the microscope slide. For materials in the composition range where phosphoric oxide is a stable crystalline phase resort was had to the dry-chamber technique used in the study of pure phosphoric oxide.[1]

The indices of refraction were measured with sodium light and the accuracy of the reported values (Table VII) is at least $\pm$ 0.002.

Previous optical studies in the system CaO-P_2O_5 were made by Schneiderhöhn,[11] who examined the phases prepared by Trömel.[2] He examined three of the seven binary crystalline phases that occur in the composition range covered by the authors in this report.

Phosphoric Oxide (P_2O_5).—Although phosphoric oxide is trimorphous,[1] only the stable, or tetragonal(?), form was observed in equilibrated charges in the system with calcium oxide. This phase develops as lath-shaped crystals with prismatic cleavage. The crystals are colorless, well-terminated and occasionally twinned. The laths exhibit parallel extinction and are length-slow (positive elongation). This polymorph is probably uniaxial and positive. The crystals are extremely reactive, even decomposing in low-melting solid immersion media. The indices of refraction are: $\omega = 1.599$ and $\epsilon = 1.624$ with ϵ-$\omega = 0.025$.

[11] Schneiderhöhn, H.: 1932, "Beiträge zur Kenntnis des Systems Kalzium-oxyde-Phosphorpentoxide. Mikroscopisch-Optische Untersuchungen der Schmelzen," Mitt. aus dem Kaiser-Wilhelm Inst. f. Eisenforschung, Düsseldorf, 14, 34-36.

The orthorhombic polymorph (metastable) was noted in one sample (composition 4) obtained by heating the glass for a relatively short time. This phase consists of colorless crystalline platey aggregates. Two cleavages were observed, a good one parallel to the optic plane and a poor one normal thereto. Optically these crystals are strongly birefringent and biaxial negative with 2V equal to about 65°. The indices of refraction are: $\alpha = 1.545$, $\beta = 1.578$, and $\gamma = 1.589$.

The hexagonal form, the one with which the chemist is familiar, is probably metastable at all temperatures. It is obtained by the rapid condensation of P_4O_{10} vapor, but it has not been crystallized from melts. The crystals occur largely as tiny colorless plates that appear to be easily deformed under slight pressure. The outline of the crystals is distinctly hexagonal, presumably made up of a prism and the basal pinacoid. Some grains appear to be trigonal in character. Polysynthetic twinning is common and may be due in part to the apparent deformability. The crystals are uniaxial positive with $\omega = 1.469$, $\epsilon = 1.471$ and $\epsilon\text{-}\omega = 0.002$.

Calcium diphosphate ($CaO.2P_2O_5$).—This compound develops as six-sided, well-defined euhedral plates. The crystals have one excellent cleavage, which is normal to the optic axial plane. Occasionally the plates are faceted with many extremely narrow forms. The crystals are biaxial and negative with a strong birefringence ($\gamma - \alpha = 0.029$). The indices of refraction are: $\alpha = 1.470$, $\beta = 1.497$ and $\gamma = 1.499$. The optic angle was found by measurement to bé 15°.

Dicalcium triphosphate ($2CaO.3P_2O_5$).—Microscopically this compound appears as nearly equant euhedral plates, each of which possesses an excellent cleavage. The crystals are biaxial and negative with 2V equal to 23°. The optic plane is perpendicular to the excellent cleavage. The indices of refraction are: $\alpha = 1.477$, $\beta = 1.511$ and $\gamma = 1.513$. The birefringence is strong, being numerically equal to 0.036.

Alpha calcium metaphosphate (α-$CaO.P_2O_5$).—Crystals of this compound occurred as euhedra in quenched charges, whereas those formed in seeded melts of large charges grew as divergent lamellae or blades. The cleavage is so pronounced in the base {001} as to cause the crystal to appear fibrous. Another cleavage, parallel to the side pinacoid (010) is of poor quality. As a consequence of the extreme degree of cleavability parallel to the basal pinacoid the grains, upon being

ground, convey the impression that the charge is wet. The cleavage and optical orientation are shown in Fig. 5. The

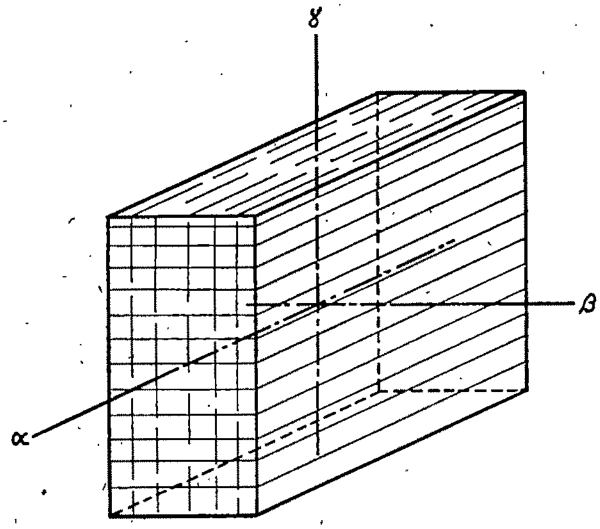

Fig. 5. Cleavage and optical orientation of α-calcium metaphosphate.

crystals are biaxial and probably negative as inferred from the indices of refraction, with 2V almost 90°. The indices of refraction are: $\alpha = 1.587$, $\beta = 1.591$ and $\gamma = 1.595$, the birefringence being 0.008. The optic plane is parallel to (010) with $Z = \gamma$, $X = \alpha$ and $Y = \beta$. Schneiderhöhn[11] found $\alpha = 1.588-$, $\gamma = 1.595$, $\gamma\text{-}\alpha = 0.007$ and $2E = 100°$.

Beta calcium metaphosphate (β-$CaO.P_2O_5$).— The habit of this phase varies with the composition of the mixture in which it forms. It crystallizes as euhedral plates and laths from melts on its stable liquidus, whereas in the region between calcium metaphosphate and calcium pyrophosphate the shape ranges from laths near the $CaO.P_2O_5$ boundary to equant plates in more calcic compositions near the pyrophosphate boundary. The optical measurements were made on Composition 23. Basal plates bounded by the prism (110) and the pinacoid (010) give rise to eight-sided crystals. The cleavage is {010} and the axial plane is parallel thereto. Extinction is parallel. The crystals are biaxial and negative. The indices of refraction are: $\alpha = 1.573$, $\beta = 1.587$, $\gamma = 1.596$ and $\gamma\text{-}\alpha = 0.023$. 2V calc. 80°.

Index measurements were made on two solid solutions: At 29.2% CaO (composition 26) $\alpha' = 1.574$, $\gamma' = 1.596$ and

γ'-$\alpha' = 0.022$; at 33.3% CaO (composition 34) $\alpha' = 1.577$, $\gamma' = 1.597$ and γ'-$\alpha' = 0.020$. The crystals were very small and orientated optical directions were not recognizable. Because of their small size and thickness the grains appeared to have a low birefringence.

Trömelite.—This phase consists of small subhedral plates without any apparent cleavage. It is usually observed as completely intergrown aggregates. The plates on end often appear fibrous. The extinction in the individual crystals is shadowy. Optical properties of this phase were determined on charges at 33.3% CaO (composition 34). The crystals developed in a charge held at 980° for 65 hours were biaxial and probably positive, as inferred from the indices of refraction, with 2V close to 90° ($2V_{graph.} = 88°$) and the indices of refraction were: $\alpha_{min.} = 1.584$, $\beta = 1.594$ and $\gamma = 1.605$ with γ-$\alpha = 0.021$. Results obtained on a charge held at 972° for 3 hours are substantially the same, being $\alpha' = 1.585$, $\beta' = 1.593$, $\gamma' = 1.606$ with γ'-$\alpha' = 0.021$.

Seven other preparations[12] were examined and found to consist of small crystals of trömelite intergrown in a complicated manner to form aggregates. The few grains appearing fairly independent exhibited undulatory extinction, so that reliable optical data could not be obtained. What appeared to be a hazy optic axis figure indicated a large 2V with $\beta' = 1.593\pm$. Some grains exhibited a very fine polysynthetic twinning. This twinning is easily confused with the frequent occurrence of lamellae of crystals and glass, which resembles polysynthetic twinning but is on a coarser scale. The scanty optical data for these materials do not permit the identification of solid solutions in this series. Furthermore, the presence or absence of this phase in a charge had to be determined by the x-ray diffraction method.

Alpha calcium pyrophosphate (α-$2CaO.P_2O_5$).—This compound forms readily as large crystals in melts. The crystals are equant and twinned polysynthetically with rather broad lamellae. In some charges a pseudopolysynthetic twinning appeared as a result of the parallel arrangement of alternate layers of glass and crystals. When such charges were reheated, they exhibited polysynthetic twinning, the previously existing

[12] Compositions 34 run 4, 35 completely crystallized at 968°, 36 run 5, 37 completely crystallized at 968°, 38 equilibrated at 949°, 41 run 1 and 42 run 6.

glass lamellae being now replaced by the missing members of the polysynthetic twins.

Optical data obtained on materials prepared in this investigation and previous results by Merwin[13] and by Schneiderhöhn[11] are collected in Table VI. The positive figure observed by Schneiderhöhn was doubtless due to an optical anomaly introduced by polysynthetic twinning. Crystals of this compound observed in the authors' small quenched charges showed in every case a biaxial negative figure. Crystallization in bulk gives rise to a mass of crystals varying widely in size with well-developed polysynthetic twinning that is easily observed megascopically. If one of the twinned plates is viewed normal to the twinning plane, a biaxial positive figure with a small 2V(ca.5°) is observed. If, however, the individual plate be crushed and a proper section normal to the optic plane be viewed, the true biaxial negative character is revealed.

Beta calcium pyrophosphate (β-$2CaO.P_2O_5$).—The *beta* modification[14] of calcium pyrophosphate forms octagonal

TABLE VI.

Optical Data for Alpha Calcium Pyrophosphate.

Author	Faust		Merwin	Schneiderhöhn
Optical character	biaxial (–)		biaxial (–)	biaxial (+)
α		1.584	1.585	1.585
β		1.599	...	...
γ		1.605	1.605	1.604
γ-α		0.021	0.020	0.019
2V		50°	small to moderate	moderate
Cleavage	good ∥ and ⊥ to optic plane		...	Imperfect in two directi

shaped euhedral crystals. These are especially well-developed in glass-bearing charges. As a consequence of the low birefringence and small crystal size sensibly isotropic grains were commonly observed. Well-developed crystals show parallel extinction and some display polysynthetic twinning. The crys-

[13] Shannon, E. V., and Larsen, E. S. 1925, "Merrillite and Chlorapatite from stony meteorites," Amer. Jour. Sci., 9, 250-260.

[14] Since this manuscript was prepared a *gamma* form, apparently monotropic with respect to the *beta* modification, to which it inverts rapidly at 700 to 800°, has been identified as the pyrophosphate that is obtained by low-temperature ignition (600°) of dicalcium phosphate. Furthermore, anhydrous calcium pyrophosphate obtained from two of the larger producers was found to be the *gamma* form.

tals are optically uniaxial and positive. The indices of refraction are: $\omega = 1.630$ and $\epsilon = 1.639$ with ϵ-$\omega = 0.009$. The crystals are tetragonal and possess a good basal cleavage with a less distinct prismatic cleavage. Schneiderhöhn described a *beta* calcium pyrophosphate, but his indices of refraction

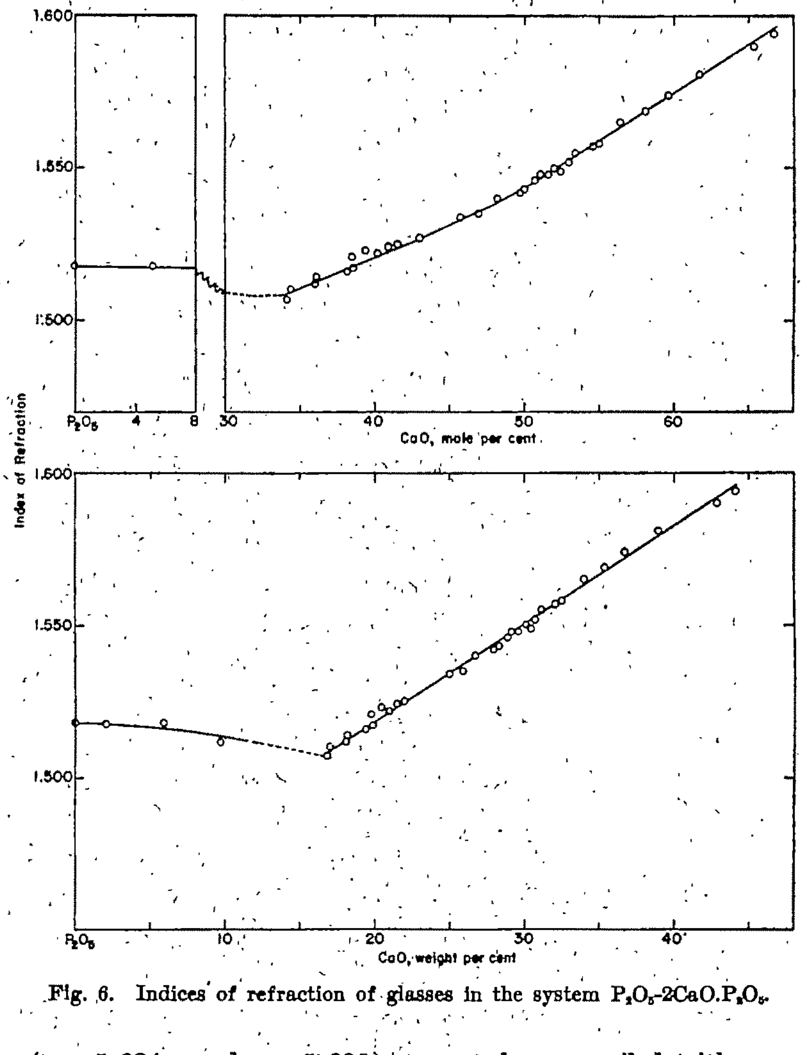

Fig. 6. Indices of refraction of glasses in the system P_2O_5-$2CaO.P_2O_5$.

($\omega = 1.624$– and $\epsilon = 1.628$) cannot be reconciled with any phase encountered by the authors.

The *beta* phase obtained by inversion of the *alpha* modification consists of interlocked crystals, which exhibit shadowy and

patchy extinction. Significant changes in the indices of refraction as a result of solid solution were not observed.

Glasses.—Optical measurements were made by the immersion method with the use of sodium light on glasses that had not been intentionally annealed. The indices of refraction of the glasses (Table IV) are plotted in Fig. 6. The lower curve, obtained by plotting the index against composition in per cent by weight, shows a marked change in slope near the diphosphate composition ($CaO.2P_2O_5$). When the composition is expressed in terms of mole per cent (upper curve), a similar change in slope occurs at the same composition with a suggestion of another in the vicinity of the metaphosphate composition ($CaO.P_2O_5$). The apparent bending of the curve at the latter composition becomes somewhat more prominent when P_4O_{10} is regarded as a mole of phosphoric oxide.

The indices of refraction of crystalline and vitreous phases, respectively, at the compositions of the several compounds are given in Table VII. These data exhibit some unusual and interesting characteristics. It will be noted that for α-calcium pyrophosphate the mean index of refraction of the crystalline solid and the index of refraction of the glass are essentially identical. This condition suggests a remarkable closeness in structural relations between the two phases. The degree of orderly organization of the atoms in the glass is approximately the same as the more regular order in the crystalline α-calcium pyrophosphate. Such a concept is in accord with other observed phenomena. As has previously been mentioned this phase is very difficult to quench to a glass and such a phenomenon would be a logical one to result from the pronounced closeness in structural relations.

The normal relation between solid and glass obtains for β-calcium pyrophosphate, trömelite, α- and β-calcium metaphosphate. The tetragonal (?) and orthorhombic forms of phosphoric oxide also belong in this category.

Calcium diphosphate and dicalcium triphosphate display the abnormal optical relation in that the glass has a higher index of refraction than the mean index of refraction of the crystalline equivalent. Moreover, the hexagonal modification of phosphoric oxide appears likewise to be abnormal. This abnormality may owe its origin to the polymerization which takes place in phosphate-rich glasses. Such polymerization may preclude the possibility of ever obtaining the index of refraction of the less polymerized glass.

TABLE VII.

Optical Constants of Crystalline Phases and Their Vitreous Equivalents.

Compound	Optical Character	2V	Birefring-ence	Indices of Refraction of Crystals						Index of Refraction of Glass
				α	ω	β	ϵ	γ	Mean [a]	
α-Calcium pyrophosphate	biaxial (−)	50	0.021	1.584		1.599		1.605	1.596	1.594
β-Calcium pyrophosphate	uniaxial (+)	0	0.009		1.630		1.639		1.633	1.594
Trömelite	biaxial (+) [b]	88	0.021	1.584		1.594		1.605	1.594	1.560
α-Calcium metaphosphate	biaxial (−) [b]	near 90	0.008	1.587		1.591		1.595	1.591	1.544
β-Calcium metaphosphate	biaxial (−)	80	0.023	1.573		1.587		1.596	1.585	1.544
Dicalcium triphosphate-	biaxial (−)	23	0.036	1.477		1.511		1.513	1.500	1.523
Calcium diphosphate	biaxial (−)	15	0.029	1.470		1.497		1.499	1.489	1.507
Phosphoric oxide (tetragonal?)	[c]	0	0.025		1.599		1.624		1.607	1.518
Phosphoric oxide (orthorhombic)	biaxial (−)	65	0.044	1.545		1.578		1.589	1.570	1.51
Phosphoric oxide (hexagonal)	uniaxial (+)	0	0.002		1.469		1.471		1.469	1.51

[a] Calculated with the aid of formulas of Larsen, E. S., and Berman, H.: 1934, "The Microscopic Determination of the Non-opaque Minerals," U. S. Geol. Survey Bull. 848, p. 81.

[b] Sign was obtained from indices of refraction.

[c] Probably uniaxial and positive.

The fertilizer properties of several of the phases and applications of the equilibrium data to the production of calcium

TABLE VIII.

Spacing Measurements and Intensities[a] for Powder Diffraction Patterns of Compounds in the System P_2O_5-$2CaO.P_2O_5$. (Nickel Kα Radiation.)

P_2O_5[b]	$CaO.2P_2O_5$	$2CaO.3P_2O_5$	α-$CaO.P_2O_5$	β-$CaO.P_2O_5$	Trömelite	α-$2CaO.P_2O_5$	β-2CaO.
		9.17 w					
				7.08 w		7.12 w	
	6.09 s						
5.68 ms		5.38 vvw					
		5.16 vs					
					4.95 vw	4.91 mw	
4.66 ms					4.77 w		4.73 vw
		4.60 s		4.57 ms			
			4.48 vw				
	4.38 ms						4.38 vw
			4.29 w	4.24 ms	4.23 w	4.24 mw	
						4.17 w	
		4.02 ms					
3.88 ms	3.83 ms	3.85 vw	3.83 w	3.84 vw	3.85 w		
						3.79 w	
			3.785 s	3.780 s	3.75 vw		
3.695 mw		3.63 mw			3.67 w	3.64 vw	
3.585 mw	3.615 w	3.60 mw			3.60 vw		
						3.54 w	
				3.510 s			
		3.465 ms	3.475 s				
					3.425 vw	3.430 vw	
3.350 m				3.375 vvw			3.350 w
		3.315 m				3.315 vs	3.320 w
			3.290 m	3.275 m			
					3.215 w	3.215 ms	3.220 m
			3.170 vw		3.180 vw		
				3.135 mw			
				3.132 mw			
			3.105 w		3.095 s	3.080 m	3.100 mw
3.030 s		3.035 ms			3.035 m		3.025 vs

[a] The relative intensities are indicated by abbreviations as follows: m for med s for strong, v for very and w for weak. Accordingly, ms should be read medium st vw very weak, etc.

[b] The stable form (probably tetragonal).

TABLE VIII.—(Continued).

O_5 [b]	$CaO.2P_2O_5$	$2CaO.3P_2O_5$	α-$CaO.P_2O_5$	β-$CaO.P_2O_5$	Trömelite	α-$2CaO.P_2O_5$	β-$2CaO.P_2O_5$
			2.975 mw	2.975 w	2.975 ms		2.970 w
	2.910 mw			2.900 vw			2.910 mw
	2.840 vvw		2.845 w	2.845 m	2.840 ms		
		2.795 w					2.800 m
65 ms				2.770 vvw		2.775 mw	
	2.750 vw	2.740 vw					2.750 m
	2.655 vw	2.655 vw	2.670 w	2.660 vvw		2.660 mw	2.680 w
				2.616 vvw			
		2.580 w	2.584 vw		2.588 mw	2.580 mw	
				2.554 m	2.534 mw		2.540 w
		2.510 vw	2.500 w		2.505 vw		
434 m			2.430 w			2.458 vw	
						2.412 vw	
						2.400 vvw	2.402 vw
326 vw		2.338 mw				2.330 vvw	2.334 w
					2.290 w		2.272 vw
					2.248 w		2.248 vw
238 vw				2.206 w			2.226 vw
			2.182 w				
146 vw						2.150 vvw	2.158 vw
			2.138 vw	2.122 w	2.130 w		2.128 vw
					2.094 w		2.090 w
065 vvw				2.056 w			
096 w							

metaphosphates fertilizer is discussed in a forthcoming article[15] from the Tennessee Valley Authority.

X-RAY POWDER DIFFRACTION DATA.

Spacing and intensity measurements on the x-ray powder diffraction photographs of the compounds involved in this system are given in Table VIII. Each compound has a unique pattern that makes possible its unequivocable differentiation from the other phases.

ALTERATION OF P_2O_5-RICH COMPOUNDS BY ATMOSPHERIC MOISTURE.

Upon exposure to the atmosphere crystalline $CaO.2P_2O_5$ and $2CaO.3P_2O_5$ react with moisture to form a new compound.

[15] Frear, G. L., Deese, E. F., and Lefforge, J. W.: 1944, "Effects of Impurities upon Fusibility, Citrate Solubility and Hygroscopicity of Calcium Metaphosphates," Ind. Eng. Chem., 36, 835.

TABLE III. Critical Quenches.

Composition No.	Run No.	Initial Condition of Charge[a]	Temperature	Time of Constant Temperature	Condition of Quenched Charge[a]	Transformation Temperature[b]
			°C.	Hours		°C
2	1	Tetr. P+CP_2+m. G	550	24	G+tetr. P	560 m
	2	do	560	42	G+tetr. P (some smokey G)	
	3	do	560	90	All G. (some smokey)	
3	1	Tetr. P+CP_2+G	505	41	G+tetr. P	
	2	do	520	48	G+m. tetr. P (corroded cryst.)	
	3	do	530	187	G+m. tetr. P " "	
	4	do	492	89	Tetr. P+CP_2+G	494 e
	5	do	495	66	Tetr. P+G	
4	1	CP_2+orthorhombic P	610	22	G+2% CP_2	614 m
	2	do	614	22	G+tr. CP_2 (poorly distributed)	
	3	do	614	46	All G (somewhat smokey)	
	4	do	485	96	CP_2+G+v.r. tetr. P	490 e
	5	do	490	89	CP_2+G	
6	1	CP_2+C_2P_3+v.r. G	800	8	G+CP_2	804 m
	2	do	805	8	All G	
	3	do	750	190	CP_2+C_2P_3+tr. G	755 s
	4	do	760	20	Crystals+r. interstitial G	
7	1	CP_2+G	796	1	G+m. CP_2	799 m
	2	do	798	1	G+tr. CP_2	
	3	do	800	1	All G	
9	1	CP_2+C_2P_3	766	1	G+tr. CP_2	767 m
	2	do	770	1	All G	

10	1	$C_2P_3+CP_2$	756	6	G+r. euhedral C_2P_3	760 m
	2	do	760	46	G+tr. crystals	
12	1	$C_2P_3+CP_2$	770	1	G+a. C_2P_3	772 m
	2	do	772	0.5	G+tr. crystals	
	3	do	774	0.5	All G	
	4	do	740	46	All crystals	745 e
	5	do	750	46	G+C_2P_3	
14	1	C_2P_3+r. β-CP	792	1	G+v.r. β-CP	796 m
	2	do	796	1	G+tr. crystal skeletons	
	3	do	800	0.5	All G	
	4	do	775	48	G+euhedral β-CP	<775 t
15	1	G+v.r. β-CP	816	0.5	G+v.r. β-CP	818 m
	2	do	818	0.5	G+tr. crystals	
	3	do	820	0.5	All G	
	4	C_2P_3+r. β-CP+r. G	772	20	C_2P_3+β-CP+r. G	774 t
	5	do	776	20	G+r. β-CP	
16	1	G+r. β-CP	840	0.5	G+tr. β-CP	841 m
	2	do	844	0.5	All G	
17	1	G+β-CP	872	0.5	G+r. β-CP	881 m
	2	do	876	0.5	G+v.r. crystals	
	3	do	880	0.5	G+tr. crystals	
	4	C_2P_3+β-CP+tr. G	772	20	C_2P+β-CP+tr. G	774 t
	5	do	776	20	G+β-CP	
19	1	β-CP+m.G	956	0.5	G+v.r euhedral β-CP	960 m
	2	do	960	0.5	G+tr. crystals	
	3	β-CP+C_2P_3+m. G	772	20	β-CP+C_2P_3+r. G	774 t
	4	do	776	20	β-CP+v.r. G	

TABLE III. Critical Quenches—(Continued)

Composition No.	Run No.	Initial Condition of Charge[a]	Temperature	Time of Constant Temperature	Condition of Quenched Charge[a]	Transformation Temperature[b]
			°C.	Hours		°C
21	1	β-CP+a.G	975	15 minutes	G+tr. β-CP	976 m
	2	do	978	15 minutes	All G	
	3	β-CP+interstitial G	780	18	β-CP coated with G	
	4	do	720	92+45	β-CP+interstitial G	
22	1	α-CP+a. G	982	1	α-CP+a. G	983 m
	2	do	984	1	All G	
	3	G	968	70	β-CP+tr. G	969 l
	4	G	970	96	α-CP+r. G	
23	1	α-CP	984	0.5	α-CP	985 m
	2	do	986	0.5	All G	
	3	β-CP	977	0.5	β-CP+G	978 m
	4	do	979	0.5	All G	
24	1	α-+tr.β-CP	983	0.5	α-CP+r. G	984 m
	2	do	984	0.5	All G	
	3	do	974	0.5	α-CP	975 s
	4	do	976	0.5	α-CP+v.r. G	
	5	do	978	0.5	α-CP+r. G	
	6	G	964	18	β-CP	965 l
	7	G	966	17	α-CP+r. G	
	8	G	968	18	α-CP	
	9	β-+r. α-CP	970	22	α-CP	
	10	α+r. β-CP	960	18	β-CP	

25	1	α-CP+r. G	980	0.5	α-CP+r. G	981 m
	2	do	982	0.5	All G	
	3	β-CP	972	0.5	Euhedral β-CP+v.r. G	975 m
	4	do	974	0.5	" " r. G	
	5	do	976	0.5	All G	
	6	α-CP	972	1	α-CP+v.r. G	971 e
	7	G	970	69	α-CP	
	8	G	968	48	β-CP	969 l
	9	β-CP	970	24	β-CP	
26	1	α-CP	970	0.5	G+a. α-CP	980 m
	2	do	980	0.5	G+r. α-CP	
	3	do	981	0.5	All G	
	4	β-CP	972	0.5	β-CP+a. G	976 m
	5	do	974	0.5	G+r. β-+tr. α-CP	
	6	do	976	0.5	G+tr. β-CP	
	7	G	970	24	α-CP	971 e
	8	α-CP	972	0.5	α-CP+v.r. G	
	9	β-CP	970	24	α-CP+tr. G	969 l
	10	do	968	24	β-CP	
27	1	α-CP+tr. trömelite	977	0.5	G+v.r. α-CP	977 m
	2	do	978	0.5	All G	
	3	do	972	0.5	α-CP+tr. trömelite+r. G	970 e
	4	G	970	24	α-CP+tr. trömelite	
	5	β-CP	972	0.5	All G	971 m
	6	"	970	0.5	β-CP+tr. G	
	7	"	968	0.5	β-CP	969 l

TABLE III. Critical Quenches—(Continued)

Composition No.	Run No.	Initial Condition of Charge[a]	Temperature	Time of Constant Temperature	Condition of Quenched Charge[a]	Transformation Temperature[b]
			°C.	Hours		°C.
28	1	α-CP+r. trömelite	978	0.5	G+r. α-CP	974 m
	2	do	976	0.5	G+v.r. α-CP	
	3	do	976	2	All G	
	4	do	972	1	α-CP+v.r. trömelite+r. G	970 e
	5	G	970	41	α-CP+r. trömelite	
29	1	α-CP+trömlite	974	4	G+r. α-CP+trömelite	976 m
	2	do	974	148	" " " "	
	3	do	976	0.5	G+tr. trömelite	
	4	do	977	0.5	All G	
	5	do	972	17	G+r. crystals	970 e
	6	G	970	42	α-CP+trömelite	
30	1	G+β-C_2P	985	0.5	G+v.r. β-C_2P	988 m
	2	do	996	0.5	G	
	3	β-CP	987	0.5	G+v.r. β-C_2P	
	4	"	970	0.5	Trömelite+r. G	969 e
	5	"	968	0.5	β-CP+v.r. trömelite	
	6	"	968	24	β-CP+r. trömelite	
31	1	G+β-C_2P	1005	0.5	G+v.r. β-C_2P (isotropic sections)	1008 m
	2	do	1007	0.5	G+tr. β-C_2P (isotropic sections)	
	3	do	1010	0.5	All G	
	4	G	970	46	α-CP+trömelite+v.r. G	970 e
	5	α-CP+trömelite+v.r. G	970	17	" " "	
	6	do	961	48	β-CP	
	7	G	961	48	"	

82	1	G	1050	0.5	G+r. β-C_2P	1053 m
	2	"	1055	0.5	All G	
	3	"	990	22	G+β-C_2P	985 t
	4	"	980	22	G+trömelite	
	5	"	975	22	" "	
	6	"	965	24	β-CP+trömelite	
	7	"	951	48	β-CP	
	8	"	690	500	β-CP+r. G	
83	1	G+β-CP	1070	0.5	G+tr. crystals	1072 m
	2	do	1070	1	" " "	
	3	do	1075	0.5	G+v.r. β-C_2P	
	4	do	1075	1	All G	
	5	Trömelite+β-CP	987	24	G+β-C_2P	985 t
	6	do	988	24	G+trömelite	
	7	do	972	0.5	Euhedral crystals in G	969 e
	8	do	970	0.5	" " " "	
	9	do	968	0.5	All trömelite	
	10	G	968	24	" "	
	11	"	965	24	Trömelite+β-CP	
	12	"	950	48	β-CP+trömelite	
	13	"	922	284	β-CP+v.r. G	
	14	"	895	528	β-CP+ca. 0.5% β-C_2P	
	15	"	690	500	β-CP+tr. β-C_2P	
84	1	G+β-C_2P	1096	0.5	G+v.r. β-C_2P	1098 m
	2	do	1100	2	All G	
	3	do	968	39	Trömelite+v.r. G	
	4	Trömelite+tr. G	970	47	Trömelite+r. G	
	5	G+β-C_2P	922	284	β-CP	
	6	Trömelite+tr. G	908	360	β-CP+r. β-C_2P	

TABLE III. Critical Quenches—(Continued)

Composition No.	Run No.	Initial Condition of Charge[a]	Temperature	Time of Constant Temperature	Condition of Quenched Charge[a]	Transformation Temperature[b]
			°C.	Hours		°C
85	1	G+β-C_2P	1125	0.5	G+tr. β-C_2P	1127 m
	2	do	1130	0.5	All G	
	3	Trömelite+tr.β-CP	986	0.5	G+a. β-C_2P	985 t
	4	do	984	0.5	Trömelite+a. G	
	5	do	972	0.5	" +v.r. G	971 e
	6	do	970	47	" +tr. β-CP	
	7	G+tr. β-CP	965	24	All trömelite	
	8	do	950	48	Trömelite+tr. β-CP	
	9	do	895	528	β-CP+β-C_2P	
86	1	G+β-C_2P	1150	1	G+tr. β-C_2P	1150 m
	2	do	1155	3	All G	
	3	Trömelite	974	0.5	Trömelite+v.r. G	970 e
	4	do	972	0.5	" "	
	5	do	970	47	Trömelite+tr. G	
87	1	G+β-C_2P	1164	19	G+tr. β-C_2P	1165 m
	2	do	1170	3	All G	
	3	Trömelite	978	0.5	Trömelite+r. G	974 s
	4	do	976	0.5	" +tr. G	
	5	do	974	0.5	" "	

38	1	G+β-C_2P	1185	0.5	v.r. α-C_2P in G	1187 m
	2	do	1190	0.5	All G	
	3	Trömelite+r.β-C_2P	984	0.5	Trömelite+r. β-C_2P+v.r. G	982 s
	4	do	980	0.5	Trömelite+r. β-C_2P	
	5	G+crystals	965	23	All trömelite	
	6	G	950	48	" "	
	7	Trömelite	925	97	Trömelite+β-CP	
39	1	Trömelite	978	407	Trömelite+β-C_2P	
	2	do	924	312	All trömelite	
	3	do	915	340	Trömelite+β-CP	
	4	do	908	360	Large β-CP peppered with β-C_2P	
40	1	β-CP+β-C_2P	1225	0.5	G+a. α-C_2P	1228 m
	2	do	1230	0.5	All G	
	3	do	987	24	β-C_2P+G	985 t
	4	do	983	24	Trömelite+β-C_2P intergrowths	
	5	G	900	48	β-CP+B-C_2P	
41	1	G+r.α-C_2P	924	312	r.β-C_2P in trömelite	
	2	do	915	340	Trömelite+v.r. β-C_2P	
	3	do	908	360	Large β-CP peppered with β-C_2P	
42	1	Crystals+G	1279	0.5	G+v.r. α-C_2P	1285 m
	2	do	1284	0.5	G+tr. α-C_2P	
	3	do	1290	0.5	All G	
	4	G+β-C_2P	1159	19	G+α-C_2P	1157 l
	5	G+α-C_2P	1156	20	G+β-C_2P	
	6	Crystals+G	924	312	Trömelite+β-C_2P	
	7	do	915	340	" "	
	8	do	895	523	β-C_2P+β-CP	

TABLE III. Critical Quenches—(Concluded)

Composition No.	Run No.	Initial Condition of Charge[a]	Temperature	Time of Constant Temperature	Condition of Quenched Charge[a]	Transformation Temperature[b]
			°C.	Hours		°C
43	1	α-+β-C_2P	1821	0.5	G+r. α-C_2P	1825 m
	2	do	1825	0.5	G+v.r. α-C_2P	
	3	do	1825	0.5	All G	
	4	β-C_2P+G	1159	19	α-C_2P+G	1157 i
	5	α-C_2P+G	1156	20	β-C_2P+G	
	6	Trömelite+β-C_2P	987	48	β-C_2P+v.r. G	985 t
	7	do	983	44	β-C_2P+trömelite	
	8	do	924	312	All β-C_2P	
	9	do	915	840	β-C_2P+v.r. trömelite	
	10	do	895	528	" " "	
	11	do	690	500	β-C_2P+ca. 0.5% β-CP	
44	1	β-C_2P+tr. G	1048	70	β-C_2P+v.r. G (rims)	1034 s
	2	do	1034	64	β-C_2P+tr. G (undevitrified G)	
	3	do	1025	40	" " " " "	
	4	do	690	500	β-C_2P, well crystallized	
45	1	α-C_2P	1845	0.5	α-C_2P+r. G	1848 m
	2	"	1850	0.5	All G	
	3	β-C_2P	1159	19	α-C_2P+tr. G	1157 i
	4	α-C_2P	1156	20	β-C_2P+tr. G	
	5	"	1154	17	" " "	1150 s
	6	"	1150	93	All β-C_2P	

46	1	α-+r. β-C_2P	1156	20	α-+tr. β-C_2P	
	2	do	1152	20	α-+r. β-C_2P	
	3	α-C_2P	1150	840	β-+tr. α-C_2P	
47	1	α-C_2P	1350	0.5	All crystals	<1357 m
	2	"	1357	0.5	α-+β-C_2P+G	
	3	"	1360	0.5	90% α-+β-C_2P+G	
	4	"	1371	1	Crystals+20% G	
	5	"	1371	1	All G	
	6	β-C_2P	1151	137	α-+v.r. β-C_2P	1140 i
	7	"	1141	570	All β-C_2P	
	8	α-C_2P	1141	570	All α-C_2P	
	9	"	1129	93	α-+r. β-C_2P	

[a] The symbols used to designate the phases are G for glass, C for CaO and P for P_2O_5, so that the meta- and pyrophosphates, for examples, are represented by CP and C_2P respectively.

The adjectives and their abbreviations used to indicate the relative amount of a phase and the roughly equivalent percentages are: trace (tr.) 0.1%, very rare (v.r.) 1%, rare (r.) 5%, minor (m.) 15%, abundant (a.) 25% or more.

[b] The nature of the transformation is indicated by a letter following the temperature: e=eutectic, i=$\alpha \rightleftharpoons \beta$ inversion, m=liquidus, t=transition, s=solidus.

This compound was observed in seven preparations (16.8 to 21.2% CaO) in amounts varying from a trace to above 50 per cent of the material, and was in each instance identified by x-ray diffraction methods as hydrated monocalcium phosphate, $Ca(H_2PO_4)_2.H_2O$. As observed microscopically this alteration product encrusting calcium diphosphate plates was fibrous or needlelike in character and optically length-slow.

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REGIONAL SUPERPOSITION ON THE SCHOOLEY PENEPLANE.

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ABSTRACT. O. D. Von Engeln has recently presented a hypothesis of origin of northern Appalachian drainage involving regional superposition of consequent southeast flowing streams from a coastal plain cover mantling the Schooley peneplane. Three lines of evidence, opposed to this date of superposition, but supporting Douglas Johnson's theory of superposition on the older Fall Zone peneplane, are (1) the absence of windgaps along some supposed former consequent stream courses but the presence of aligned groups of windgaps well preserved along others, (2) the presence of shallow ridge crest sags into which watergaps have been incised, and (3) the remarkably even inner margin of the coastal plain.

A HYPOTHESIS of regional superposition of Atlantic slope drainage has been outlined by O. D. Von Engeln in a recent textbook of geomorphology.[1] Although similar in all other major points to Douglas Johnson's theory of regional superposition,[2] the newer explanation postulates that the Schooley peneplane, rather than the Fall Zone peneplane, was buried under a coastal plain cover. Von Engeln believes that if superposition had occurred on the earlier Fall Zone surface, transverse stream courses would by now have been diverted, and all evidences of superposition long since removed. Only the point of difference between the two drainage histories will be discussed.

Superposition upon the Schooley peneplane is not a new idea. Johnson carefully considered the possibility and rejected it for cogent reasons. His evidence for assigning coastal plain overlap to the Fall Zone peneplane rather than to the Schooley peneplane is as follows:

1. If superposition had occurred from a coastal plain cover overlapping the Schooley peneplane, the entire superposed drainage system should be capable of reconstruction by connecting aligned groups of windgaps.[3] Every transverse stream, as it became superposed across resistant rock layers

[1] Von Engeln, O. D.: 1942, Geomorphology, The Macmillan Company, New York, 339-368.

[2] Johnson, Douglas: 1931, Stream Sculpture on the Atlantic Slope, Columbia University Press, New York.

[3] Johnson, Douglas: op. cit., 35-36.

would have cut a series of watergaps. Even if the stream were diverted soon after superposition, the resultant windgaps would remain as evidence of its former course. For although Schooley ridge crests, including watergaps, may have been somewhat modified and lowered by weathering, no later cycle of peneplanation has removed the ridge crests or obliterated the gaps. Such aligned windgaps as do exist are in fact beautifully preserved, and clearly record post-Schooley diversions of remnants of superposed consequents which persisted in initial courses through watergaps cut in the ridges until after the end of Schooley time. The fact that few courses of former superposed consequent streams can now be reconstructed indicates that superposition must have occurred long before the close of the Schooley cycle, during which the countless windgaps developed by diversions in that cycle were obliterated.

2. A second important line of evidence was discovered and interpreted by Ver Steeg.[4] A longitudinal profile of the crest of Kittatinny Mountain and other Pennsylvania ridges reveals that the highest elevations are at points between the major transverse drainage lines, with the undulating ridge crest descending toward major gaps. The watergaps and windgaps were found to have been incised into the centers of shallow sags on the ridge crest. These facts, together with other points of evidence,[5] strongly support the interpretation that the ridge crest represents the Schooley peneplane and that transverse streams were in their places at the close of the cycle. Both conclusions have been utilized by Johnson as independent and unexpected confirmation of a pre-Schooley date for regional superposition.[6]

Ver Steeg's conclusions have not, however, been accepted by H. D. Thompson and Von Engeln. Thompson has argued that gentle ridge crest slopes toward watergaps are normal features of erosion in folded mountains; that they are the result of greater reduction of ridge crests near the master drainage lines and therefore provide no justification for assuming either a pre-Schooley or later superposition.[7] Von Engeln[8] accepts this view in preference to that of Ver Steeg.

[4] Ver Steeg, Karl: 1930, Annals N. Y. Acad. Sci., 32, 87-220; 1940, Amer. Jour. Sci., 238, 685-709; 1942, Jour. Geol., 50, 504-511.

[5] Ver Steeg, Karl: 1940, op. cit., 694-695; 1942, op. cit., 506-507.

[6] Johnson, Douglas: op. cit., 43-44.

[7] Thompson, H. D.: 1939, Geol. Soc. Amer., Bull. 50, 1330.

[8] Von Engeln, O. D.: op. cit., 357.

Thompson and Von Engeln seem to have disregarded certain important evidence and arguments repeatedly emphasized by Ver Steeg.[9] The crest of Kittatinny Mountain and other ridge crests show two distinct features, each with its particular significance:

(A) Elevations of the undulating ridge crests are greatest between major transverse drainage lines, but diminish to a minimum at the major gaps. To describe this feature in such terms as "a discernible slope toward the watergaps" may be misleading because it is neither a smooth, constantly descending profile line, nor is it sufficiently marked to be seen in the field. Ver Steeg has interpreted the undulating ridge crest as the low monadnock ridge which stood somewhat above the Schooley peneplane developed on adjacent weak rock belts. Slower reduction of the land surface at major divide areas caused this monadnock ridge crest to be highest at those divides and to descend gradually to the principal transverse streams. Under this interpretation superposition from a coastal plain blanketing the Schooley surface is ruled out because superposed streams would stand an infinitely small chance of retaking positions coinciding perfectly with the lowest points on the ridge between the fossil divides.

Thompson and G. H. Ashley[10] hold that the same variations of ridge crest elevations would develop in a single cycle of erosion because of faster reduction of the ridge nearer to the larger and lower drainage lines. Inasmuch as exactly the same principle is back of the lowering of ridge crests with relation to drainage lines in both the Ver Steeg and Ashley-Thompson interpretations, this particular line of evidence, standing by itself and with all other lines of evidence disregarded, may permit either view.

(B) A second ridge crest characteristic has also been described and interpreted by Ver Steeg.[11] On both sides of many watergaps and windgaps the ridge crest within one or two miles of the gap slopes with a gentle (2° to 5°) but distinctly visible declivity toward the gap. These slopes constitute a broad, shallow sag into which the stream has cut the deep V-gap. If the gentle slopes are projected upward away from the gap they will be seen to pass far above the present

[9] Ver Steeg, Karl: 1930, op. cit., 91-92, 104, 218; 1940, op. cit., 689, 692-695; 1942, op. cit., 509.

[10] Thompson, H. D.: op. cit., 1930; Ashley, G. H.: 1935, ibid, 46, 1395-1436.

[11] Ver Steeg, Karl: 1930, op. cit., 90-91, 218; 1942, op. cit., 509.

undulating ridge crest and are thus clearly distinguishable from the first ridge crest feature described above. It is these sags which form the critical evidence for the existence of the Schooley peneplane and for a pre-Schooley date of origin for the streams. Not only are notched sags unexplainable in a single cycle of erosion, but it is virtually impossible that by chance superposition so many streams could have occupied the centers of sags if that peneplane had been buried under a coastal plain mantle. Thus both Ashley's and Thompson's interpretations of a single-cycle development of all topographic features, and Von Engeln's hypothesis of superposition on the Schooley peneplane are equally opposed by Ver Steeg's evidence.

3. A third point used by Johnson as evidence of pre-Schooley superposition has also been noted by Von Engeln,[12] but not fully applied to his hypothesis of Schooley superposition. If the coastal plain had overlapped upon the Schooley surface, remnants of those sediments should still be preserved as outliers far inland from the Fall Line. The inner margin of the coastal plain would thus be a ragged zone. Instead, the coastal plain terminates along a remarkably even line, with few, if any, important outlying remnants. The presence of a later erosion surface truncating both the older basement rocks and the coastal plain strata, with consequent absence of coastal plain remnants inland from the line of intersection of basement plane and later (Schooley) peneplane, is clearly indicated.

The block diagrams used by Von Engeln to illustrate regional superposition from a coastal plain mantling the Schooley peneplane[13] are apparently modified, with change of orientation, from the series of diagrams designed by Johnson to illustrate his text,[14] although the source is not stated. Failure to modify the original diagrams to meet the needs of the newer hypothesis properly has resulted in serious error. Von Engeln's first diagram, which shows Appalachian drainage before coastal plain overlap and superposition occurred, strangely enough already has direct, southeast flowing drainage. How it acquired that course, transverse to the structure, is not explained. With such a stream system already present, the need for superposition is removed. This is clear from the fact that the new drainage resulting from superposition, shown in a later dia-

[12] Von Engeln, O. D.: op. cit., 357.
[13] Von Engeln, O. D.: op. cit., 358-361.
[14] Johnson, Douglas: op. cit., 15-20.

gram, is essentially identical in character with the assumed initial drainage. The mistake has resulted from using, without due care, Johnson's diagram of the Schooley peneplane upon which superposition has already occurred, instead of his diagram of the Fall Zone peneplane, which is the corresponding step. Alterations in minor details of Johnson's diagrams have led to further errors, such as representation of the Triassic rocks as limestone instead of sandstones, shale, and trap.

In summary, Von Engeln's proposed modification of Johnson's hypothesis of regional superposition from coastal plain strata is strongly opposed by evidence obtained from the distribution of windgaps, from the form of ridge crests, and from the nature of the inner coastal plain margin.

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SCIENTIFIC INTELLIGENCE

Physics.

Principles of Physics I; by F. W. Sears. Pp. 526; profusely illustrated. Cambridge, Mass., 1944 (Addison Wesley Press Inc., $5.00).—The Massachusetts Institute of Technology has for some time introduced its students to the subject of physics in a two-years course, the first of which covers the subdivisions of Mechanics, Heat, and Sound. The present book is a text used in this part of the introductory course. Its numerous virtues are in considerable measure traceable to the freedom of exposition which this two-year presentation of the subject of physics affords. By its leisurely pace it avoids estranging the student at the very beginning, and this fault is in my opinion the major cause why elementary students, taking the ordinary one-year introductory course, generally dislike physics. "Difficult" subjects, such as uniform circular motion and simple harmonic motion, are treated relatively late in the course, at a stage when the student may be presumed to have attained mastery of the necessary physical principles as well as the mathematics.

The arrangement of subject matter represents a fortunate compromise between a rigid logical sequence desirable in advanced courses, and the usual conglomeration characterized by the rule of "easy things first." The author's purpose is best expressed by quoting from the preface: "The emphasis of the book is on physical principles. Historical background and practical applications have been given a place of secondary importance." There can be no quarrel with the execution of this program; it is well achieved. But perhaps the wisdom of omitting practical applications to the rather extreme extent to which they are absent in this book may be questioned.

This defect, if it be a defect, is largely compensated, however, by remarkably well selected sets of problems, many of which stimulate the student by their intrinsic interest, many dealing with practical applications. Most illustrations are simple and clear line drawings. An outstanding feature of the book is its use of instructive multiflash photographs, admirably suited to illustrate complex motions. There is no better way of demonstrating the physical meaning of center of mass and of center of percussion than by the beautiful reproductions on pages 105 and 277.

As to contents: "The book opens with several chapters on statics in order that kinematics may be postponed until the student has acquired some familiarity with the concepts and notation of calculus. Beginning with Chapter 4, simple differentiation and integration are introduced to supplement and extend the algebraic development of

the equations of linear motion with constant acceleration. From that point on, the calculus is used freely wherever its inclusion is warranted."

In the matter of units, the book is highly ambitious, for it uses three systems throughout: the English gravitational, the C. G. S. and the M. K. S. system. One wonders—in spite of the author's very plausible justifications—whether this was not done to make the book suitable to the tastes of the widest possible number of teachers who, most unfortunately, have not yet adopted any unique stand on this matter. No student should be introduced to all three at the beginning, and we fear that inclusion of them all in this book will tend to be confusing.

The spirit of the discussion is refreshingly modern; some sections (e.g. that on surface phenomena) correct errors which have been propagated by elementary textbooks for decades. But why "the reader is advised to accept [the theory of intermolecular forces] with reservations" (a sentence occurring on p. 310 in an otherwise excellent discussion), is not at all clear to this reviewer.

The text makes no typographic distinction between scalar and vector quantities; equations involving the addition of vectors are followed invariably by the cumbersome phrase "vector sum." There is no reason whatever why a course in physics using vectors, even if it is an elementary course, should not employ the conventional black-face type for vector quantities. My experience has shown that elementary students are happy about this distinction and find it far less harassing than the needless use of Greek letters, for example.

Finally, to mention minor points, the book contains no satisfactory definition of mass. A derivation of the ideal gas law, which appears on p. 456 et seq., operates in most elementary style with a cubical box, a single speed of all molecules, and assumes them to vibrate in three groups along the axes. At this stage, a student who has studied the preceding material and has thus far had the benefit of the author's careful explanation, would be expected to prefer a somewhat more adequate and elaborate derivation. H. MARGENAU.

CHEMISTRY.

Wood Chemistry; edited by LOUIS E. WISE. Pp. x, 900. American Chemical Society Monograph Series No. 97. New York, 1944. (Reinhold Publishing Corp., $11.50).—In recent years, the interest in wood and the products obtainable from it has increased very greatly. The war conditions which brought this about comprise not only economic changes, but also personal displacements. New

discoveries have contributed, directly, and indirectly, by drawing attention to older ones. Obviously, our publishers are well aware of these facts. Within the last few months, at least three important books on this subject have appeared: "Cellulose and Cellulose Derivatives," under the editorship of Emil Ott and reviewed here a short time ago, Emil Heuser's "Chemistry of Cellulose," and the book under review here. This last one, in which fourteen eminent authors present the several aspects of the subject, gives a more complete picture of the chemical behavior of wood itself than the other two. In view of these, it might even have gone farther in this respect, thereby avoiding some overlapping with the others in the chapters on cellulose.

The general plan for such a book will always reveal compromises because of the overlogical complexities of the subject and the preferences of the authors. It was logical to begin with "The growth, anatomy, and physical properties of wood" as Part 1; but should the "Surface properties of cellulosic materials" not follow immediately, instead of forming Part 4? Part 6 deals with "Wood as an industrial raw material" and contains a chapter on "The chemical behavior of wood" which might have found its place even before the present Part 2 on "Components and Chemistry of the cell wall." The other parts are No. 8, "The extraneous substances," and 5, "The chemical analysis of wood."

Each one of the 25 chapters, from Harry P. Brown's "Growth and Anatomy of Wood" to Selman A. Waksman's "Decomposition of Lignin" (by micro-organisms), is a monograph in itself, presenting, within the necessary limits of space, a practically complete description of its subject. This book will be eagerly received by the many chemists and engineers whose work has to do with wood, and by the still greater number of those who may want to find out what this field still has to offer.

The references, among which those to patents are very scarce, are given at the end of each chapter, in alphabetical order of the authors. Many will find this method rather cumbersome. The system of a science is usually not very closely related to the alphabetical system of our letters. This is one reason why the 40 pages of Subject Index cannot compensate for the fact that the table of contents is extremely short. Additional such tables, preceding the individual chapters, would certainly be helpful.

In general, one might wish that the editor had found it desirable to create closer coordination between the parts of the book. We are somewhat inclined to amputate from our scientific books the links which connect the pieces of specialized research. Are not the relations between these parts and their meaning essential constituents of the scientific work? EDUARD FARBER.

Geology.

Geologic Importance of Calcareous Algae, with Annotated Bibliography; by J. Harlan Johnson. Quarterly of the Colo. School of Mines, vol. 38, no. 1. Pp. 102, 28 figs. Golden, Colorado, 1943 ($1.50).—It is now recognized that calcareous algae play an important rôle in the formation of modern calcareous deposits in the sea and in some freshwater lakes. They are generally associated with corals and in some so-called coral reefs far exceed other organisms in the formation of limy deposits. Furthermore, such algae are widely distributed beyond the limit of coral reefs.

It is not surprising, therefore, that calcareous algae are present in many calcareous formations and have been important rock-makers since Precambrian time and that they are believed to have played a prominent part in the formation of such massive limestone deposits as the Capitan reef in Texas and parts of the Dolomite Alps. It is notable that under these circumstances the study and description of fossil algae have been so badly neglected in this country. Doctor Johnson's work in this field is therefore the more welcome.

The present volume is largely a bibliography of works on fossil algae and will be a great aid in any future studies on this group.

CARL O. DUNBAR.

Foreign Maps; by Everett C. Olson and Agnes Whitmarsh. Pp. xvii, 237; 25 text figs., 16 plates in color. New York and London, 1944 (Harper and Brothers, $4.00).—Anyone who makes frequent use of foreign maps will find this volume a good investment. Even the professional geologist or geographer, with much experience, will find parts of it indispensable for frequent reference. The work is devoted to geographic maps, particularly those indicating relief; it does not touch upon the interpretation of geologic maps. A general discussion of maps of the United States, embodied in the first chapter, forms a good background for the rest of the book.

Chapters 2, 3, and 4 are devoted to methods of reading foreign maps and consider such matters as different types of signs and symbols, grid systems, scales and measurements, and index systems.

Language difficulties, treated in Chapters 5 and 6, take up about one-third of the volume. Such objects as streams, hills, bridges, docks, and a hundred more may be indicated in the foreign tongue and, unless these words are translated, the map cannot be fully understood. Few persons will be familiar with more than a few tongues, and if the map be in Japanese, Bulgarian, Arabic, or any one of a score of others, the difficulty of translating the legends may be great. To meet this need, Chapter 5 presents a glossary of the terms likely to be encountered on a map for each of 37 different languages.

Signs and symbols used by different language groups form the subject matter of Chapter 7; scales and measurements are treated in Chapter 8; and grid systems in Chapter 9. Certain characteristics of the maps of the principal foreign mapping agencies are summarized in Chapter 10, and the final section includes a bibliography and a list of the chief catalogues and reports including maps of the different countries.

While the book may be used by the student to gain an understanding of foreign maps, it will also serve as a constant reference work even for the experienced professional map user. CARL O. DUNBAR.

PALEONTOLOGY.

An Avifauna from the Lower Miocene of South Dakota; by ALDEN H. MILLER. University of California Publications, Bulletin of the Department of Geological Sciences, vol. 27, no. 4, pp. 85-100, 8 text-figures. Berkeley and Los Angeles, 1944 (University of California Press, price 25 cents).—The author finds recognizable ten forms among an exceptionally large number of avian fossils in the fauna from Flint Hill in the Lower Miocene of South Dakota. Of these the new forms are *Megapaloelodus connectens* (new genus and species), first Tertiary flamingo to be found in North America, described from the distal end of the right tarsometatarsus and a crushed left femur; *Dendrochen robusta* (new genus and species), extending northward the range of tree-ducks, described from complete left humerus and distal ends of two additional humeri; *Querquedula integra* (new species), a teal, nearly complete right coracoid and left ulna; *Ortalis pollicaris* (new species), a chachalaca, proximal third of left tarsometatarsus; *Tympanuchus stirtoni* (new species), prairie chicken, proximal third of left tarsometatarsus; *Miortyx teres* (new genus and species), quail, proximal three-fourths of right humerus; *Strix dakota* (new species), a small owl "with a foot as thoroughly specialized as that of living owls," described from the distal three-fourths of the right tarsometatarsus. Remains of a previously known duck (*Paranyroca magna*), a vulture (*Palaeoborus rosatus*), and an indeterminate buteonine hawk also were found in the collection.

"The fauna was deposited in a stream channel lens of silt in which the remains of vertebrates were mixed and concentrated. Preservation of the small bones of birds and mammals is excellent . . .

"The fauna comprises, in addition to a group of North American types, an Old World element and a Neotropical element, each consisting of two forms. Several notable extensions of groups in geological time are recorded.

"Ecologically the fauna consists of aquatic and woodland facies, suggesting the presence of large streams and lakes adjoined by

riparian woodland and perhaps fairly extensive woods or forests on the uplands."

The paper is illustrated with excellent line drawings.

S. C. BALL.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Studies in the Anthropology of Oceania and Asia Presented in Memory of Roland Burrage Dixon; edited by CARLETON S. COON and JAMES M. ANDREWS, IV. (Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 20.) Pp. xiv, 220; 10 maps, 7 figures and 20 plates. Cambridge, 1943 (Peabody Museum, $4.50)—This is a collection of fourteen papers written by former students of the late Professor Dixon of Harvard University and prefaced with a biography and a bibliography of his works. Reflecting Dixon's interest in the ethnic history of the east, the articles are primarily concerned with racial and cultural movements in a territory stretching from Polynesia to western Siberia and Arabia. The emphasis is upon physical anthropology, but the archaeologist and the ethnologist will also find much of importance in this volume.

In the field of physical anthropology, there are articles on racial characteristics in Polynesia, Melanesia, India, Siam, Japan, and southern Arabia. The first two of these, by Harry L. Shapiro and W. W. Howells, should be particularly useful as summaries of the distribution of races in Oceania, as well as for their theories of migration. More provocative, perhaps, is James M. Andrews' discussion of Siam, which departs from the general theme of the volume to compare changes in body build among the Thai, Japanese immigrants into Hawaii, and New England college students. It is suggested that similar changes among these people may be due to the operation of similar evolutionary and environmental factors, of which nutrition is stressed.

For the archaeologist, the volume contains two papers on Polynesia, one on China and another on Siberia. Two of these are likely to be frequently consulted, Kenneth P. Emory's "Polynesian Stone Remains" because it summarizes the results of a comprehensive research program undertaken by the Bishop Museum of Honolulu, and James H. Gaul's "Observations on the Bronze Age in the Yenesei Valley" because it makes available to western archaeologists the findings of Russian research in an area of key importance for the diffusion of culture between Europe, China and possibly also through northeastern Siberia into the New World. Gaul's paper is also significant for his critical analysis of theories as to the origin of the so-called "animal style" of art.

The areas discussed ethnographically include Rennell Island and

southern Bougainville in Melanesia, northeastern Australia, Madagascar and southern Arabia. Douglas L. Oliver contributes a penetrating comparison of religious concepts in southern Bougainville, while Carleton S. Coon's summary of the present status of our knowledge about southern Arabia is noteworthy for its indications of relationships with India on the east and Africa on the west.

Since Dixon himself was noted more as a scholar than as a field worker, it is surprising to find that the reverse is true of this volume. Several of the articles reveal an incomplete knowledge of other research in the areas studied: for example, Frederick S. Hulse's discussion of "Physical Types among the Japanese," fails to take into consideration the recent work of Japanese archaeologists in Korea, Manchuria and Mongolia which has a direct bearing on theories as to the origin of the Japanese people. On the whole, however, the volume is a fitting tribute to one of the greatest of American anthropologists. IRVING ROUSE.

Clouds and Weather Phenomena; by C. P. J. CAVE. Pp. 28; 42 plates. New York and Cambridge, 1943 (The Macmillan Co., $1.75).—Clouds interest everybody. Most people try to use them as a means of foretelling the weather. Captain Cave of the Royal Engineers, who has twice been president of the Royal Meteorological Society, knows how to talk about them. Into a few pages he packs a surprising amount of information, and does it in a most interesting and effective way. The new edition of his little book on clouds should be left on the table with current magazines so that everybody aged eight to eighty may pick it up and then go outside and speculate as to whether the clouds are cirrus or stratus, altocumulus or cirrostratus. There will be diversities of opinion, but all will agree when the clouds are nimbus. ELLSWORTH HUNTINGTON.

Spherographical Navigation; by DIRK BROUWER, FREDERICK KEATOR, and D. A. MCMILLEN. Foreword by Captain P. V. H. Weems. Pp. xxiii, 200; 21 figs. New York, 1944 (Macmillan Co., $5.00).—This little book explains a small invention due to a big one. The big invention is the airplane; the small one is an improved way of using the heavenly bodies as a means of finding out where one's plane is located. The new method, like the old, begins with measuring the altitude of a star, the sun, the moon, or a planet with a sextant, and noting the exact time according to Greenwich. Then, according to the old method one went to the Nautical Almanac, searched in various tables, did some calculating, and finally obtained an answer in degrees and minutes of latitude and longitude. The new method cuts out the calculating and simplifies the use of the tables.

This desirable end is accomplished by means of a globe about seven inches in diameter with a surface on which pencil marks can

readily be made and erased. Attached to the globe, and snugly fitting it, is a moveable ruler pivoted on the poles. The equipment is completed by another curved ruler, like the first, but detached so that it can be placed at any angle and position, and by a drawing compass and a protractor, both of which are also curved to fit the globe. The authors say that with these instruments and a sextant it is a matter of only a few minutes to discover just where a plane or ship is located, with an error of no more than two minutes of arc (about two miles). A skilled navigator can learn to use the device in a few hours, and a totally unskilled one in a few weeks with much greater ease than he could learn the old method.

The inventor of this spherographical method of navigation was Mr. McMillen, the third author mentioned on the title page. He worked with Mr. Anton Stuxberg, a Danish astronomer at the observatory in Sao Paulo, Brazil, but neither of them had the technical knowledge necessary to develop their invention. Mr. McMillen remembered that his Yale professors had such knowledge. Therefore, he appealed to the University. Doctor Brouwer, Director of the Astronomical Observatory, and Professor Keator of the Department of Mechanical Engineering, were interested, and wrote this little book to tell people how to use the new device. The book begins with a good, clear account of the earth as a globe, the celestial sphere, and methods of plotting a ship's course. It ends with actual examples of the construction of spherographs.

ELLSWORTH HUNTINGTON.

Soil and Plant Analysis; by C. S. PIPER. Pp. xiv, 368; 19 figs. New York, 1944 (Interscience Publishers, $4.50).—This book, a reprint of a monograph from The Waite Agricultural Institute, University of Adelaide, South Australia, is a laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants.

Methods for measuring the properties usually considered in soil and plant analysis are presented clearly and in sufficient detail so the laboratory worker need not refer to the sources. However, selected references to the literature are given at the end of each chapter to facilitate checking original publications when that is desired. The methods presented are in actual use in the laboratories of the Waite Institute and are reported to give accurate and reliable values for a wide range of soil and plant materials.

Two indices are provided, one for part 1 dealing with soil analysis and one for part 2 dealing with plant analysis.

The author has developed an extremely useful laboratory manual which will be appreciated by all who are concerned with the physical and chemical properties of soils or with determination of the inorganic elements in plants. H. J. LUTZ.

PUBLICATIONS RECENTLY RECEIVED.

Kansas Geological Survey. Bulletins as follows: 52, Part 8. Coal Resources of the Kansas City Group, Thayer Bed, in Eastern Kansas; by W. H. Schoewe. 54. Exploration for Oil and Gas in Western Kansas during 1943; by W. A. Ver Wiebe. Lawrence, 1944.

Mississippi Geological Survey. Bulletin 58. Geology and Ground-water Resources of the Camp Shelby Area; by G. F. Brown. University, 1944.

Illinois Geological Survey. Report of Investigations as follows: 91. An Annotated Synopsis of Paleozoic Fossil Spores and the Definition of Generic Groups; by J. M. Schopf, L. R. Wilson, and R. Bentall. 97. Corals from the Chouteau and Related Formations of the Mississippi Valley Region; by W. H. Easton. Bulletin No. 68. Some Addresses and Papers presented on the occasion of the Dedication of the State Natural Resources Building, November 15, 1940, and The Illinois Mineral Industries Conference, November 14-16, 1940. Urbana, 1944.

New Mexico School of Mines. Bulletins as follows: 19. Manganiferous Iron-Ore Deposits near Silver City, New Mexico; by L. P. Entwistle. 20. Stratigraphy of the Colorado Group, Upper Cretaceous, in Northern New Mexico; by C. H. Rankin. Socorro, 1944.

A Shorter History of Science; by Sir William C. Dampier. New York, 1944 (Macmillan Co., $2.00).

Dana's System of Mineralogy. Centennial Anniversary Issue 1844-1944. Vol. 1, Elements, Sulfides, Sulfosalts, Oxides. Seventh edition; by C. Palache, H. Berman and C. Frondel. New York, 1944 (John Wiley & Sons, $10.00).

Dictionary of Organic Compounds. Edited by I. M. Heilbron, et al. Volume I, revised. Price $30.00. Supplements for Volumes II and III, $1.00 each. New York, 1944 (Oxford University Press).

U. S. Geological Survey. 53 Topographic Maps.

Chemical Machinery; by E. R. Riegel. New York, 1944 (Reinhold Pub, Corp., $5.00).

New Hampshire Mineral Resource Survey. Part 8, Sillimanite Deposits in Monadnock Quadrangle, New Hampshire; by K. Fowler-Billings. Price $.10, Concord, 1944.

Chemical Analysis, a Series of Monographs on Analytical Chemistry and its Applications. Vol. III. Colorimetric Determination of Traces of Metals; by E. B. Sandell. New York, 1944 (Interscience Pub. Co., $7.00).

Magnetochemistry; by P. W. Selwood. New York, 1944 (Interscience Pub. Co., $5.00).

Luminescence of Liquids and Solids and its Practical Applications; by P. Pringsheim and M. Vogel. New York, 1944 (Interscience Pub. Co., $4.00).

A New Manual for the Biology Laboratory; by B. R. Weimer and E. L. Core. New York, 1944 (John Wiley & Sons, Inc., $2.00).

Mississippi Geological Survey. Bulletin 57. Monroe County Mineral Resources. Geology; by F. E. Vestal. Tests; by T. E. McCutcheon. University, 1943.

Kansas Geological Survey. Bulletin 53. McLouth Gas and Oil Field, Jefferson and Leavenworth Counties, Kansas; by W. Lee and T. G. Payne, Lawrence, 1944.

Vegetable Fats and Oils; by G. S. Jamieson. Second edition. New York, 1943 (Reinhold Pub. Corp., $6.75).

Colloid Chemistry. Theoretical and Applied. Collected and edited by Jerome Alexander. Vol. 5. Theory and Methods, etc. New York, 1944 (Reinhold Pub. Corp., $20.00).

American Journal of Science

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GEOLOGIC OBSERVATIONS IN THE UPPER SEVIER RIVER VALLEY, UTAH.*

HERBERT E. GREGORY.

CONTENTS.

ABSTRACT. The East Fork and South Fork valleys of the Sevier River roughly coincide with the trend of the Sevier and Paunsaugunt faults that outline the Sevier Plateau, and mark borders of the Markagunt and Aquarius Plateaus. Along the faults, in the slopes and escarpments produced by uplifts of 600 to 2,000 feet, the Tertiary rocks characteristic of southern Utah are exposed: the pink limestones of the Wasatch formation (Eocene); the white tuffs and gray igneous conglomerates of the newly recognized Brian Head formation (Miocene ?); the widely spread andesitic lavas; and, in places, the gravels of the Sevier River formation (Pliocene ?). In Antimony Canyon erosion has revealed Jurassic and Cretaceous strata. From south to north the Wasatch limestones and the overlying stratified pyroclastics of the Brian Head formation decrease in thickness and the igneous conglomerates increase to thicknesses of exceeding 1,000 feet.

* Published by permission of the Director, United States Geological Survey.

INTRODUCTION.

DURING the course of detailed field work in the adjoining districts[1] brief investigations were made of the geologic features along the two major branches of the Sevier River: the East Fork between Antimony and Widtsoe, and the South Fork in the vicinity of Panguitch. Within these valleys particular attention was given to the western flanks of the Aquarius and the Sevier Plateaus, where, in consequence of large-scale faulting and differential uplift, the edges of the sedimentary strata and the extrusive volcanics are displayed in normal sequence.

Dutton mapped in broad outline the structure and sedimentary formations in the region under review and discussed the character and extent of the pyroclastics and lavas. Gilbert studied the regional relations of the Sevier and adjoining Markagunt plateaus and determined the position and effect of the Sevier fault. In more recent years the geologic features of Antimony Canyon, particularly with reference to its economic resources, have been described by Richardson, Butler and Duncan. Specific citations appear in the following pages.

GEOGRAPHIC SKETCH.

The topography of the district, which includes the upper branches of the Sevier River, is essentially the same as that of the High Plateau of central Utah: huge, massive, cliff-bordered blocks of rock, tilted generally northeastward, trenched by deep gorges, and outlined by faults of large displacement. At its western rim the Sevier Plateau, which lies between the Sevier fault and the Paunsaugunt fault, stands at an altitude of 10,000 to 10,500 feet—more than 4,000 feet above the South Fork of the Sevier River at Panguitch. From this height the plateau surface slopes for 18 to 20 miles to its termination at the Paunsaugunt fault where its edge is concealed beneath alluvium in the valley of the East Fork. Likewise the precipitous western rim of the Aquarius Plateau, which attains heights exceeding 10,500 feet, rises 3,500 to 4,000 feet above the valley at its base (see Figs. 1, 2.)

In this region the ancestral drainage system, developed on

[1] Gregory, H. E., and Moore, R. C.: 1931, The Kalparowits region, U. S. Geol. Survey Prof. Paper 164. Gregory, H. E.: The Paunsaugunt region, U. S. Geol. Survey Prof. Paper (in preparation).

broad surfaces of low relief, has been disorganized by regional and local uplifts, tilting, and faulting, and the lapsed time since the disturbances occurred is insufficient to have permitted complete readjustment. In consequence most of the streamways are ungraded; along their courses in unsystematic succession

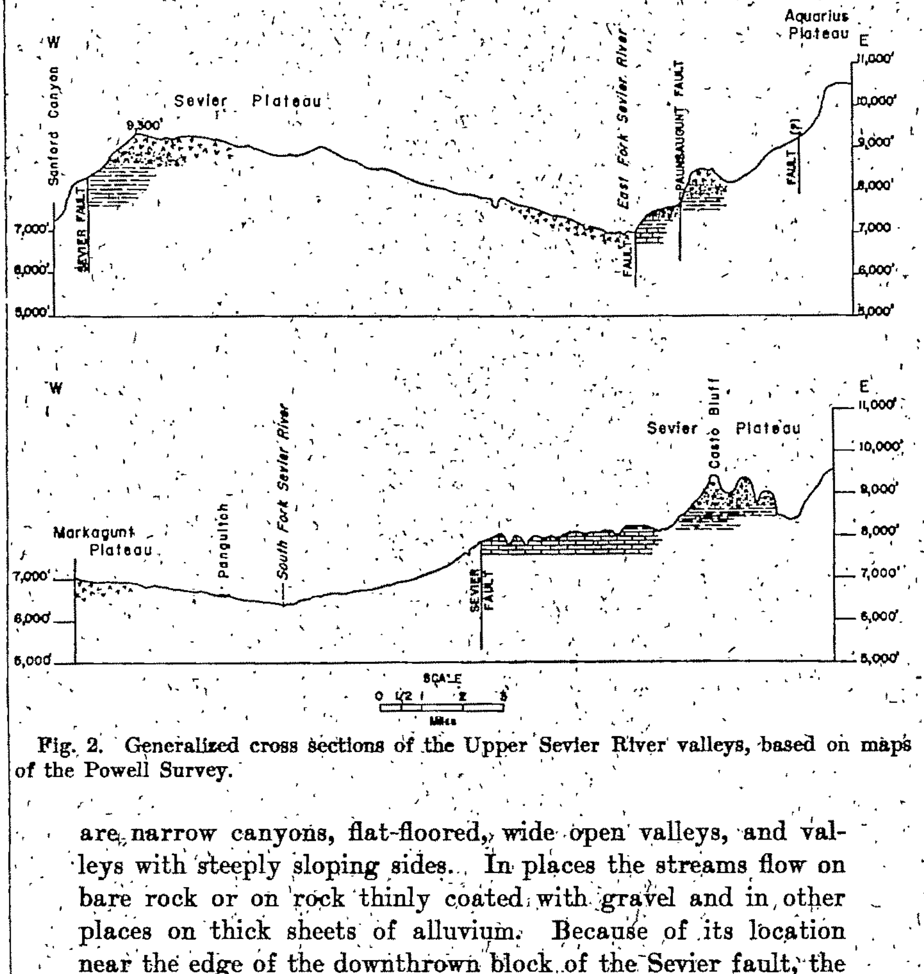

Fig. 2. Generalized cross sections of the Upper Sevier River valleys, based on maps of the Powell Survey.

are narrow canyons, flat-floored, wide open valleys, and valleys with steeply sloping sides. In places the streams flow on bare rock or on rock thinly coated with gravel and in other places on thick sheets of alluvium. Because of its location near the edge of the downthrown block of the Sevier fault, the South Fork of the Sevier flows past Panguitch in a valley made flat by thick lacustrine and stream deposits that merge with alluvial fans banked high along the base of the Sevier Plateau. On leaving the zone of faulting the river traverses the deep Circleville Canyon, then crosses the flat Circle Valley. Likewise the East Fork of the Sevier where it lies near the Paunsaugunt fault meanders across flat lands between low walls of alluvium. On its course west of the fault the stream traverses the narrow

Black Canyon, then in turn the meadow lands about the village of Antimony, the deep, rock-walled Kingston Gorge, and finally an alluvial flat. The average gradient of the South Fork below the mouth of Red Canyon is about 24 feet to the mile; of the East Fork below Widtsoe, 31 feet to the mile, but in their steepest stretches the gradients are as much as 120 feet to the mile.

Because of topographic control the form and gradient of the tributary streamways is unlike those of the master channels. The western tributaries of the Sevier have gentle gradients; most of them flow in shallow trenches on bare rock. On the other hand, the eastern tributaries occupy short, steep, narrow canyons that head abruptly at the plateau rims. Throughout their courses in the canyons Casto, Limekiln, Sanford, and Smith Creeks, tributary to the South Fork, and Birch, Cleaves, Center, and Antimony Creeks, tributary to the East Fork, have gradients of 400 to 800 feet a mile. The South Fork of the Sevier is through-flowing. Its eastern tributaries are permanent in their upper courses and at times of floods carry water across their alluvial fans; but, except for Panguitch Creek, which drains a large part of the well-watered Markagunt Plateau, its western tributaries are ephemeral. The East Fork, through Emery Valley and parts of Johns Valley, is intermittent; the combined flow of a score of tributaries from the back slope of the Sevier Plateau and the front of the Aquarius Plateau is insufficient to maintain a continuous stream. At the head of Black Canyon the East Fork receives contributions from the spring-fed Deer Creek, and more from springs farther down the canyon. But the chief contributor to its waters is Antimony Creek, which occupies the longest, deepest, crookedest, and most intricately branched of the canyons that dissect the western flank of the Aquarius Plateau. Formerly the creek entered a lake where its waters, together with those of the East Fork of the Sevier, were ponded while farther north in Kingston Gorge a stream was sinking its channel through the resistant volcanics of the Sevier Plateau to a depth sufficient to provide a continuous outlet.

As agents of erosion both forks of the Sevier River are relatively inefficient; they are chiefly engaged in widening their runways in unconsolidated sand and gravels. In contrast, the streams that flow down the precipitous fronts of the Sevier and Aquarius plateaus are vigorously scouring bed rock, trans-

porting talus, and removing from their channels the alluvial débris deposited during a previous physiographic cycle. Their work is facilitated by the flash floods and seasonal floods that characterize the stream runoff in the High Plateaus of Utah.

The plant life in the upper valleys of the Sevier River is that characteristic of the rugged plateau lands of central Utah. The types of vegetation are related to altitude and the consequent range in temperature and amount of precipitation, but the normal zonal arrangement is much modified by the conditions of insolation imposed by the height and position of canyon walls, the erratic distribution of perennial streams and springs, and the wide range in altitude of areas of bare rock and fertile soil. The complex vertical and horizontal arrangement of gorges, stream flats, slopes, cliffs, and plateau tops naturally provides local habitats with little regard to contour lines. At altitudes above 8,000 feet the most common trees are yellow pine, replaced at the highest levels by spruce and fir. Beautiful groves of aspen and scattered clumps of manzanita, mountain mahogany, and shrub oak are common. Interspersed with the pines and extending to altitudes below them, widely spaced junipers and piñons stand in fields of vigorously growing sage brush. In the lower valleys sage brush, rabbit brush, and introduced weeds are dominant, and immediately along water courses box elder, birch, willow, cottonwood, clematis, grape, and "bullberry." In distribution the vegetation is "patchy." Expanses of matted grasses, of sod, and of closely spaced trees mingled with dense underbrush are small and rare. On the broad glaciated summit of the Aquarius Plateau treeless glades, hundreds of acres in area, are features of the forest lands. Most of the canyon walls and many steep slopes are substantially bare of vegetation (see Pls. 1, 2, 4, 6).

The region that includes the upper valleys of the Sevier River is primarily "stock country." During the summer months the cattle and sheep find palatable brush, grasses, and weeds on the highlands and the natural meadow lands along streams. When snow covers the ground the livestock either return to the home ranches where hay is provided, or migrate to the warmer lowlands along the Colorado River. To conserve forage, most of the Sevier, Aquarius, Paunsaugunt, and Markagunt plateaus is included in the Powell National Forest. For general agriculture the conditions are unfavorable. The growing season is short, the precipitation small and erratically

distributed in time and place, and the surface runoff, chiefly from melting snows, supplies few streams with water sufficient for profitable irrigation. At Panguitch the average period without killing frost is but 80 days (June 15-September 8); the mean annual rainfall is 9.69 inches. At Antimony the growing season is 72 days, the annual rainfall 8.13 inches—in some years less than 5 inches.

Irrigation farming is profitable at Panguitch, where 3,850 acres are watered by 3 canals leading from Panguitch Creek and the South Fork of the Sevier River; also at Antimony, where the run-off from Antimony Creek and East Fork of the Sevier makes possible the irrigation of 2,557 acres, given over chiefly to the cultivation of potatoes and forage crops. At ranch homes along the base of the Aquarius Plateau, along Sanford, Sweetwater, Horse, Birch, Branch, and Center creeks, a few acres are "under ditch" but irrigated lands at the mouths of Casto, Limekiln, Sand, and Smith Canyons, and in Emery Valley and Johns Valley have been abandoned, and attempts to develop dry farming at Henderson resulted in costly failure.

The only mineral of economic importance is stibnite, which has been mined intermittently since 1880 without substantial profit.

STRATIGRAPHY.

General Relations.

Most of the consolidated sedimentary rocks in the upper valleys of the Sevier River are representatives of well known Mesozoic and Cenozoic formations that characterize the plateau province: Shinarump conglomerate and Chinle (?) formation of Upper Triassic age; Navajo sandstone of Jurassic (?) age, Carmel formation, Entrada sandstone, Curtis (?) formation, and Winsor (?) formation of Jurassic age; Dakota (?) sandstone and Tropic formation of Upper Cretaceous age; and Wasatch formation of Tertiary age. In addition to these widely exposed stratigraphic units measured sections include tuffs, igneous agglomerates, breccias, and flows that mark the southern border of the large Tertiary volcanic field of central Utah. These interbedded lavas and proclastics conform in regional attitude with the ordinary sedimentary strata and thus in the development of the topography have exercised no peculiar control. The partly consolidated sediments include the Sevier River formation of the late Pliocene or early

Pleistocene age, Pleistocene drift and lacustrine marls, and Recent stratified sands deposited along streams, and the jumbled débris of alluvial fans piled at the west bases of the Sevier and the Aquarium plateaus.

MESOZOIC DEPOSITS.

Distribution.

Along the upper branches of the Sevier River, sediments of Triassic, Jurassic, and Cretaceous age are exposed only at the northwestern edge of the Aquarius Plateau where in an area of about 6 square miles they form the walls of Antimony Canyon and its many branch gorges. The rocks in this small area are peculiarly isolated; the nearest of corresponding age lie northeast of the Aquarius, south of the Paunsaugunt, and west of the Markagunt plateau at distances of 35 to 70 miles (see Pl. 3).

The geologic features of Antimony Canyon have been described in general terms by Dutton[2] and more recently with particular reference to mineral resources by Richardson,[3] Butler,[4] and Duncan.[5]

Dutton states:

> The northwestern angle of the Aquarius is laid open by an immense gorge.[6] A mass of lavas and conglomerates more than 2,000 feet thick is revealed, and beneath them the Tertiary. Near the opening of this gorge the Grass Valley fault [northern extension of the Paunsaugunt fault] cuts across it, throwing down the platform to the west.

In agreement with Dutton, Richardson assigned the sediments in Antimony Canyon to the Tertiary—a conclusion adopted also by Butler and his associates. In his pioneer report on the ore deposits, Richardson writes:

[2] Dutton, C. E.: 1880, Report on the geology of the High Plateaus of Utah; U. S. Geog. Geol. Survey Rocky Mt. region, pp. 299, 295.

[3] Richardson, G. B.: 1908, Antimony in southern Utah; U. S. Geol. Survey Bull. 340, pp. 253-256.

[4] Butler, B. S., and others: 1920, The ore deposits of Utah; U. S. Geol. Survey Prof. Paper 111, pp. 561-563.

[5] Duncan, D. C.: Antimony deposits in Antimony Canyon, Garfield County, Utah; U. S. Geol. Survey; manuscript on file.

[6] This gorge is shown on Dutton's maps as Mesa Canyon. To the pioneer settlers it was known as Coyote Canyon and the town site near its mouth, Coyote. In recognition of the mining interests, the postoffice at Coyote was renamed Antimony (1921), and this term is now generally applied also to the canyon.

At the base of the section there is 150 fe
composed of rounded pebbles of quartz and
in diameter, in a sandy matrix. The congl
a great mass of fine-textured buff and reddi
ordinate drab and red sandy and clayey
limestone, amounting in all to several hun
No fossils have been found in these rocks
lithologic resemblance to Eocene strata els
region they are provisionally referred to that

The report by Duncan, though chiefly
ment of the occurrence, quality, and pote
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exposed rock units in which appears 1,5(
sediments, not previously recognized. Ir
series of massive sandstones and thin-bedd
and limestones classed as undifferentiated
includes arenaceous and calcareous strate
to sheets of lava. Regarding these
remarks

The Jurassic beds are unconformably ove
red, buff, and gray sandstones and shales, gr
ate and light-gray limestone, which totals a
These beds were considered to be of Eoce
and are probably equivalents of the Wasa
recognized in nearby areas. The known an
area are confined to a sandstone and shale zo
near the middle of the formation. Middle
rocks mostly dense acidic flows, with some a
overlie the Wasatch (?) formation. The volca
to be about 1,000 feet thick.

Thus Duncan, accepting the conclusion
ardson, records thick Tertiary but no
However, beds of Cretaceous age—possil
age—are present, and Tertiary rocks othe
believed to be absent. In brief, the Mesoz
walls of Antimony Canyon are character

Upper Triassic Strata

The conglomerate exposed in the walls o
(a southern tributary to Antimony Cree
the rock elsewhere recognized as the Shina

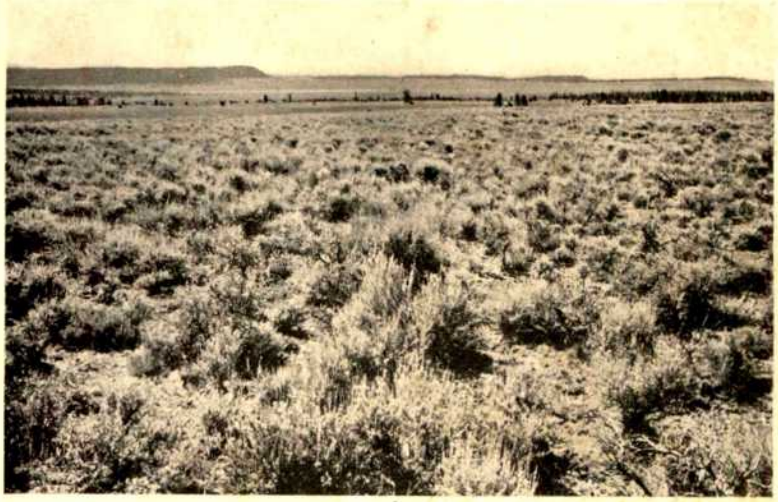

Plate 1. View looking across the upper East Fork Valley in the vicinity of Widtsoe. Flat land developed by the deposition of alluvium on maturely eroded surface of Wasatch formation Altitude 7,000 feet. Vegetation chiefly sage, annual compositae, and (near the stream channel) yellow pine. Photograph by U. S. Forest Service.

Plate 2. A park in the Powell National Forest, Aquarius Plateau, near the head of Antimony Canyon, altitude 10,000 feet. The surface has been scoured by glaciers.

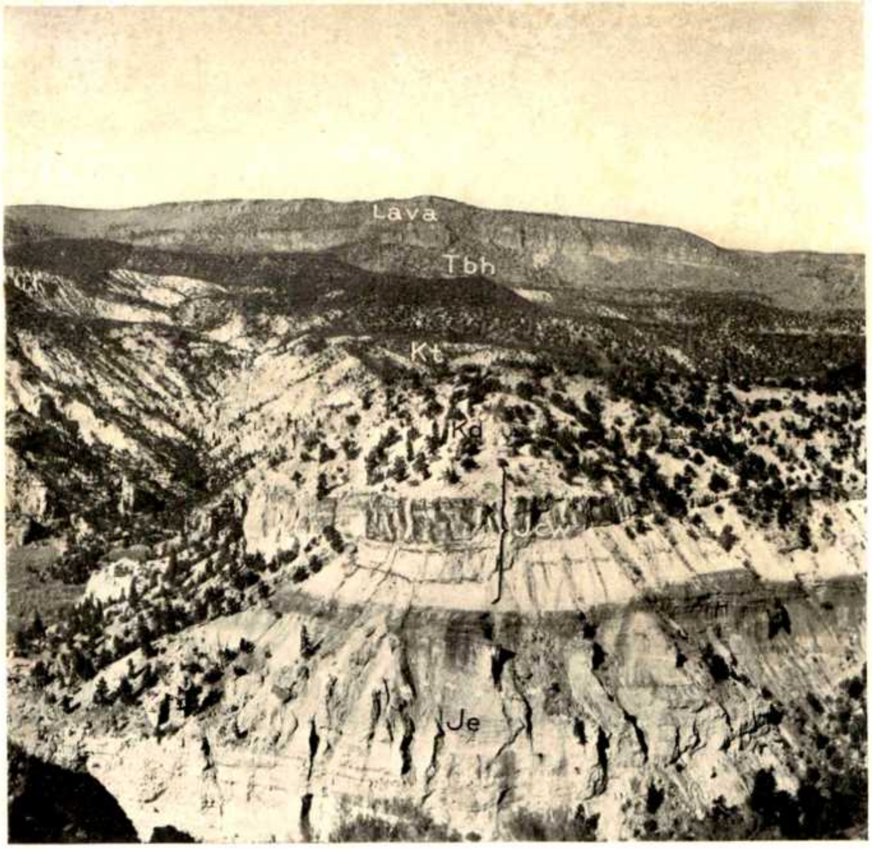

Plate 3. View of formations exposed on the northwest face of Aquarius Plateau near the mouth of Antimony Canyon. Je, Entrada sandstone; Jcw, Curtis and Winsor formations; Kd, Dakota (?) sandstone; Kt, Tropic formation; Tbh, Brian Head formation. Lavas, Tertiary andesites that form the top of Aquarius Plateau. Photograph by D. C. Duncan.

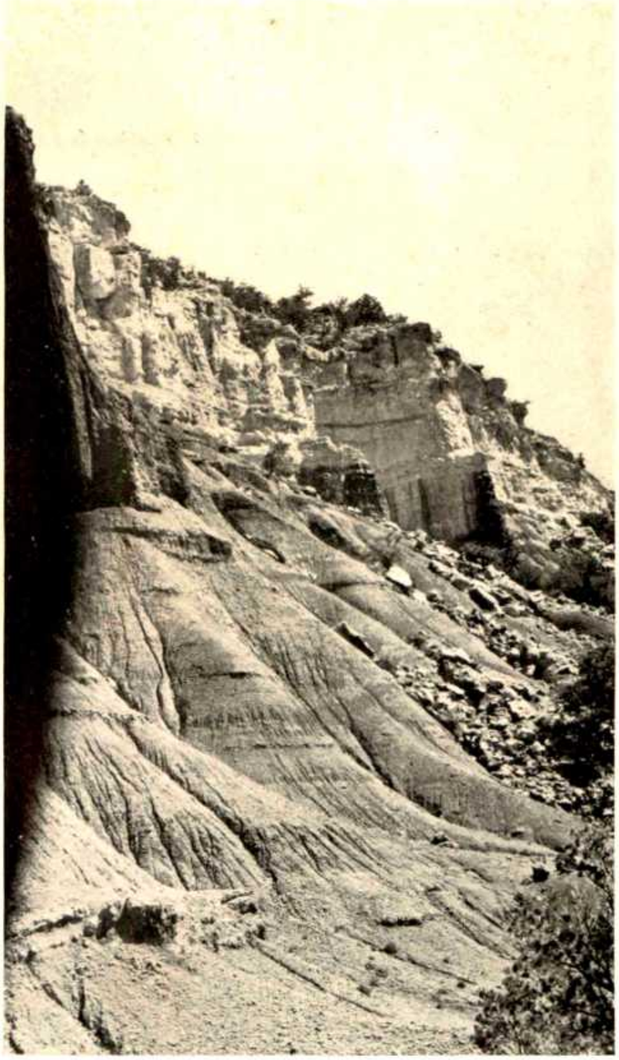

Plate 4. Entrada sandstone and overlying Curtis (?) formation in the north wall of Antimony Canyon.

Plate 5. Typical view of the Tropic formation near the southwest rim of Antimony Canyon.

Plate 6. Strata exposed in the wall of Casto Canyon. Bedding and style of erosion is characteristic of the pink limestones in the Wasatch formation.

and in texture and composition it is unlike the other coarse-grained rocks in the Antimony region. Its coarser parts consist almost wholly of smoothly rounded quartzite and quartz pebbles 1 to 5 inches in diameter embedded in quartz sand and gravel; its finer parts of short lenses of stratified sandstone. Fossil wood seems to be absent. The conglomerate lies within a zone traversed by a series of roughly parallel fractures and its contacts with beds below and above, both concealed, are probably fault planes.

On both sides of Antimony Creek near the mouth of its canyon, strata, possibly Upper Triassic in age, are pressed tightly against a lofty ridge of sandstone. In a gully north of the creek the outcrop is a sequence of varicolored shales and sandstones that dips westward at angles of 30° to 50° and constitutes a block between faults; on the east it is in contact with massive red sandstone and on the west with sheeted lava. Roughly the exposed rocks are divisible into three groups of beds; brown and tan, thin bedded sandstones (at the base); red arenaceous shales; and greenish argillaceous shales. But within these groups color, composition, texture, and style of bedding are not persistent. In places the brighter colors appear as blotches and streaks; some beds otherwise uniform in texture include flakes and concretions of clay and aggregates of gypsum crystals. The beds at this small isolated exposure lack features clearly recognizable as diagnostic of any formation known elsewhere, and in the absence of fossils and of formations in normal stratigraphic sequence above and below their age is uncertain. Their component shales and sandstones would not be out of place in the lower part of the Chinle formation, which in Utah is highly variable in content, and as they lie in a zone of cross faulted strata they possibly may be fragments of Chinle oriented in some undetermined fashion. However, the structural relations indicate an age younger than the Triassic. The beds are on the downthrow side of a fault, in contact with the upthrown Middle Jurassic (?) Navajo sandstone and may therefore be downfaulted fragments of Upper Jurassic formations, which, like the Chinle, includes rocks widely diverse in composition and origin.

Middle Jurassic (?) Strata.

The deposits classified by Duncan[7] as undifferentiated Juras-

[7] Duncan, D. C.: op. cit.

sic in Antimony Canyon include "white, gray, and tan quartzitic sandstone . . . 950 to 1,200 feet thick"—a stratigraphic unit identifiable as the Navajo sandstone. Its physical features substantially duplicate those displayed by the Navajo elsewhere in the Colorado plateau province and described in many geologic reports. It is a massive, thick-bedded, in large part cross-bedded, stratum, composed essentially of cleanly washed, small, spherical quartz grains, uniform in size and weakly cemented by calcium carbonate and iron oxide. It includes a few thin lenses of calcareous silt and scatterd fragments of magnetite and metamorphic minerals. Unlike its usual attitude—a flat-lying bed terminated by cliffs—the Navajo sandstone in Antimony Canyon stands nearly vertical, forming a high, narrow ridge through which Antimony Creek has cut a deep gorge—a conspicuous scenic feature of the local topography. From its crest the ridge descends precipitously 600 feet to the flat lands along lower Antimony Creek. Eastward it slopes steeply downward 500 feet to Black Jack Creek, along which the relatively soft Upper Jurassic rocks have been worn into gullies, rounded ridges, and low rock terraces. The sandstone mass is bordered by faults of large displacement and crossed and recrossed by minor fractures so close-spaced and unsystematically orientated that much of the rock seems shattered.

Upper Jurassic Formations.

In Antimony Canyon rocks of Upper Jurassic age include the Carmel formation, the Entrada sandstone, and an undifferentiated unit that probably represents the Curtis and the Winsor formations. At its western edge the Carmel stands in vertical position in fault contact with the Navajo sandstone and elsewhere dips steeply eastward. Likewise the other Upper Jurassic formations are upturned along their western edges at angles of 5° to 30° but generally conform with the regional northeast dip of 2° to 5°.

The Carmel formation, in addition to its characteristic compact, gray-blue marine limestone and interbedded hard calcareous shales, includes more than the usual amount of thin red sandstones and green, gray, and maroon shales.

The Entrada sandstone, though meagerly exposed, is a very

conspicuous stratigraphic unit: its edges are displayed as vertical cliffs decorated by grooves and columns, and its color—deep red streaked with yellow—strongly contrasts with the gray of the formations above and below. The sandstone is arranged in thin, somewhat irregular beds, more evenly foliated near the base, and consists dominantly of fine quartz grains weakly cemented by lime and iron. Irregularly interbedded are lenses of gray white and greenish calcareous, slightly gypsiferous sandstone which on weathered slopes project as shelves (see Pl. 4). Thus parts of the Entrada in Antimony Canyon resemble the generally massive cliff-making sandstone of like age in the Waterpocket fold and along Glen Canyon and other parts the strata in the Parunuweap and Virgin Valleys, which are remarkably uniform in composition and bedding and contain much gypsum.

The Jurassic sediments above the Entrada sandstone are thought to represent the Curtis and the Winsor formations, though in general appearance they are unlike either of these formations as expressed elsewhere and no persistent features serve to mark a division plane between them. The lower part of the undifferentiated unit contains the roughly bedded sandstones, thin hard limestones, and lenticular conglomerates commonly present in the Curtis, but lacks the thick beds of gypsum which generally in Utah constitute the bulk of the formation. In the middle part lenses of fine conglomerate, calcareous nodules, and other minor features of the typical Winsor are recognizable but no duplicates of the remarkable color banding, the uniformity of bedding, and the peculiar basal conglomerates that characterize the formation at its typical exposures. In the upper part the style of bedding, the texture, and the composition resemble rare features of the Winsor formation in the Zion Park region.

Fossils in the Upper Jurassic beds in Antimony Canyon are representative of the Carmel and the Curtis (?) faunas. In collections from arenaceous limestone beds near their contact with the Navajo sandstone, John B. Reeside, Jr. found a Carmel fauna: "*Ostrea strigilecula* White, *Pleuromya* sp., *Trigonia cf. T. americana* Meek, *Dosinia jurassica* (Whitefield)?, and *Camptonectes stygius* White" and recognized broken shells in lenticular gray limestone above the Entrada sandstone as "fragments of *Camptonectes* sp., *Ostrea* sp., *Pinna* sp., and other fossils of Jurassic age."

Cretaceous Formations.

The Cretaceous strata in Antimony Canyon are prominently exposed. Along Antimony Creek and 10 or more tributaries they combine in forming cliffs and steep slopes little encumbered by talus and dense vegetation and because of their light color they are readily distinguishable from the nearly black igneous rocks that mark their upper limit and the dark red Entrada sandstone near their base. In distant view the upper half of the Cretaceous slopes appears to be wholly shale and the lower half shale irregularly interbedded with thick sandstones and throughout the exposure the bedding indicated by slightly projecting benches or faintly outlined by color seems to be regular. However, closer examination shows that shale, thin sandstones, and thick, massive sandstones are unsystematically interbedded, that in all classes of sediments few beds retain their individuality for as much as 1,000 feet and that in addition to quartzose, argillaceous, and calcareous sandstone, the unit includes arenaceous, gypsiferous, calcareous, and rarely carbonaceous shale, limestone, bentonite, and conglomerate, all commonly in lenticular beds. Thus in general appearance the Cretaceous rocks in Antimony Canyon are unusual, but in variety of sediments and style of bedding they closely resemble the Dakota (?) sandstone and the Tropic formation which make up the lower part of Cretaceous sections in adjoining parts of Utah. Outstanding differences are the color tones and the scarcity of carbonaceous material. In Antimony Canyon the Cretaceous rocks are green-gray, yellow, and light tan, in contrast with drab, brown, and dark gray common elsewhere; a few carbonaceous sandy shales that contain partly carbonized plant fragments, and a reported "layer of muddy coal" are the meager representatives of the many coal beds in corresponding positions at other Cretaceous outcrops. Another noteworthy feature is the absence above the Tropic formation of thick strata like the Wahweap and Straight Cliffs sandstones, and the Mesa Verde and Kaiparowits formations—a group of units that 40 miles distant in Paria Valley make up the topmost 2,000-3,000 feet of the Cretaceous deposits. These absent strata are believed to have been worn away during a long period of denudation that removed also the overlying Tertiary limestone of the Wasatch formation (see Pls. 3, 5).

In contrast with their abundance in the Jurassic strata,

fossils in the beds of Cretaceous age of Antimony Canyon are extremely rare. They were found only in a few lenses of calcareous, speckled black and gray sandstone 10 to 30 feet above the conglomeratic Dakota (?) sandstone and include no complete forms. In the collection submitted for determination Reeside noted,

"a number of fragmentary specimens of a gastropod that suggest *Pachymelania chryssaloides* White, of the early Upper Cretaceous Bear River formation of southwestern Wyoming [the equivalent of the Dakota (?) and the lower Tropic formation in Utah]. I have compared the specimens with the various Coniobasis of the Eocene. It does not match any of them."

TERTIARY FORMATIONS.

Composition and Relations. Except for the Triassic (?), Jurassic, and Cretaceous rocks in Antimony Canyon, the consolidated sediments along the upper branches of the Sevier River belong to the Tertiary and Quaternary systems. In ascending order they comprise the Eocene Wasatch formation; the Miocene (?) Brian Head formation and overlying sheets of igneous rock; the late Pliocene or early Pleistocene Sevier River formation; Pleistocene silts and marls; and Recent alluvial stream terraces and fans. Of these stratigraphic units the Wasatch, the Brian Head, and the lavas extend without interruption into the regions outside of the Sevier valleys, the younger formations are restricted to areas where topographic control has been favorable.

WASATCH FORMATION. (*Eocene*).

Along tributaries to the upper Sevier River the Wasatch formation consists essentially of thick bedded, fresh-water, pink limestone which generally at its base and sporadically above includes lenticular conglomerates of well-worn quartzite, chert, and igneous pebbles. In general appearance, in composition, texture, color, and manner of erosion the bulk of the formation differs little from rocks of this age in adjoining regions. Its exposures in Casto, Limekiln, Sweetwater, and Horse Canyons substantially duplicate those in Red Canyon and in the Pink Cliffs of the Paunsaugunt and Markagunt plateaus which have been mapped and described in detail.[8] Differences concern

[8] Gregory, H. E.: The Paunsaugunt region, Utah; U. S. Geol. Survey Prof. Paper [in preparation].

chiefly its extent, its relation to superjacent formations, and the origin and composition of its upper part—the so-called white Wasatch. Northward from the latitude of Widtsoe on the East Fork and from Casto Canyon on the South Fork, the pink limestone of the Wasatch rather rapidly decreases in thickness; the white limestone beds become more and more siliceous and even tuffaceous until they are indistinguishable from the dominantly pyroclastic Brian Head formation. Regionally the upper part, known as the white Wasatch, and the equally white lower part of the Brian Head formation occupy the same stratigraphic position. Characteristic features of the Wasatch formation are shown in Pl. 6.

Along the Paunsaugunt fault which marks the western edge of the uplifted Aquarius Plateau the thick-bedded pink limestone of the Wasatch in Sweetwater Canyon is about 1,100 feet thick: above it lies about 400 feet of white almost pure limestone in thin uneven beds. Northward in Horse and Birch Canyons the exposed pink limestone of the Wasatch is 520 feet thick and the so-called white Wasatch, here highly siliceous and rich in chalcedony, 120 feet thick. At Cleaves Gulch the corresponding units are respectively 70 + feet and 130 feet. Farther north along the edge of the Aquarius Plateau the Wasatch, if present beneath the alluvial fans, doubtless continues to decrease in thickness, for in Antimony Canyon both the pink limestone and the overlying siliceous white rock are absent; igneous conglomerate and lava immediately overlie Cretaceous shales. Likewise west of the Paunsaugunt fault the thickness of the Wasatch decreases northward from 1,800 at Bryce Canyon to about 800 feet in Prospect Canyon. Still farther north none is exposed in the canyons that trench the eastern slope of the Sevier Plateau and in Kingston Gorge, where the East Fork of the Sevier has cut a trench over 1,000 feet deep, only igneous rocks are in sight. These stratigraphic relations of the Wasatch along the East Fork of the Sevier River are duplicated along the South Fork in the upthrown block of the Sevier fault. In the walls and upper slopes of Casto Canyon the pink limestones of the Wasatch and the white siliceous shales above them attain a combined thickness of about 1,600 feet, then thin rapidly northward across Petersen, Limekiln, and Sand canyons and are not represented in Sanford, Smith, or Bulrush canyons, nor farther north in the deep

Circleville or Lost Creek canyons, which are walled in by pyroclastics and lavas. Callaghan[9] states that "no rocks assigned to the Wasatch formation crop out in the Marysvale region." This decrease northward in exposed thickness of the Wasatch is in part due to its northward dip, which is greater than the inclination of the bordering valleys, and in part to shearing by faults, but in greater part it is probably the record of erosion.

It thus appears that within the area occupied by the northwestern Aquarius, the northern Sevier Plateau, and the adjoining Awapa plateaus and the Tushar Mountains, the Eocene Wasatch sediments if ever present had been erased by erosion before the middle Tertiary igneous conglomerates and lavas were laid down. It seems worthy of note that the plane—in places an unconformity—that separates the calcareous sediments and the volcanics dips northward and northwestward while the lavas and accompanying beds of igneous conglomerates lie nearly flat. As if to maintain a uniform combined thickness, the volcanics progressively thicken to compensate for the thinning and final disappearance of the limestone. Their regional distribution suggests that the older volcanics in Central Utah spread southward from a source in the northwestern Sevier Plateau and the adjoining Tushar Mountains—areas in which Tertiary non-volcanic sediments are largely lacking and latite and related lavas, tuff, ash, volcanic breccia, and igneous agglomerates are piled to depths exceeding 3,000 feet.

BRIAN HEAD FORMATION [*Miocene (?)*].

General Features and Relations.

Generally along the upper branches of the Sevier River wherever all the Tertiary formations are exposed, the conspicuous pink limestones of the Wasatch are overlain by an equally conspicuous series of white, calcareous, and siliceous shale-like beds and in turn by gray, igneous agglomerates which in places form the surface of the plateaus and in other places extend upward to capping sheets of black lava. On the Paunsaugunt and the southern Aquarius plateaus the white strata immediately below the conglomerates are essentially lime-

[9] Callaghan, Eugene: 1936, Volcanic sequence in the Marysvale region, Utah: Am. Geophysical Union Trans. for 1939, pt. 3, p. 441.

stones; some of them wholly calcareous, others more or less siliceous. On the Sevier, the northern Aquarius, and the central Markagunt plateaus equivalent strata consist chiefly of volcanic ash, tuff, and highly siliceous limestones and contain much chalcedony. Naturally these conspicuous tuffaceous beds—in places brightly colored and beautifully carved—attracted the attention of Dutton,[10] who treated those exposed in "Sanford Canyon" (Limekiln Gulch ?), and Kingston Gorge as records of volcanic activity and the beds elsewhere in the Sevier valleys in the same stratigraphic position and more or less similar in composition as "lacustrine limestones"—the "upper white limestones and calcareous marls" . . . "the summit of the Bitter Creek Group" (Wasatch formation in part). Dutton[11] writes,

> [At Sanford Canyon] the strictly eruptive part of the [Sevier] Plateau ends, and the continuation of it southward is composed of Tertiary beds of the Bitter Creek group, overlaid by an enormous mass of volcanic conglomerate. Between the two are thin layers of those fine-grained marls and sandstones which have been derived from the decay of ancient lavas, and which were evidently deposited in water. Of the age of these intermediate beds it is possible to say but little. They are apparenly conformable to the Bitter Creek below, but the conformity is no proof of continuity of deposition. They contain no fossils. . . . . Veins of chalcedony and agate often cut the beds, and the fragments strew the soils and badland at the foot of the cliffs.

In more recent reports on the southern High Plateaus the white strata that generally overlie the pink limestones and include pure calcareous silts, siliceous limestones, calcareous sandstones, and volcanic ash have been treated as a phase of Wasatch deposition. In the present paper these stratified beds are classed as the lower part, and the coarse igneous conglomerates above them as the upper part, of the Brian Head formation, tentatively considered Miocene in age. The name is derived from Brian Head, a prominent projection of the Markagunt Plateau near the Cedar Breaks National Monument.[12]

[10] Dutton, C. E.: 1880, Report on the geology of the High Plateau of Utah: U. S. Geog. Geol. Survey Rocky Mt. region, pp. 73-74, 158-159, 199, 237-238.

[11] Dutton, C. E.: op. cit., pp. 237-238, 73-74.

[12] Gregory, H. E.: Geology of eastern Iron County, Utah; U. S. Geol. Survey Prof. paper (in preparation).

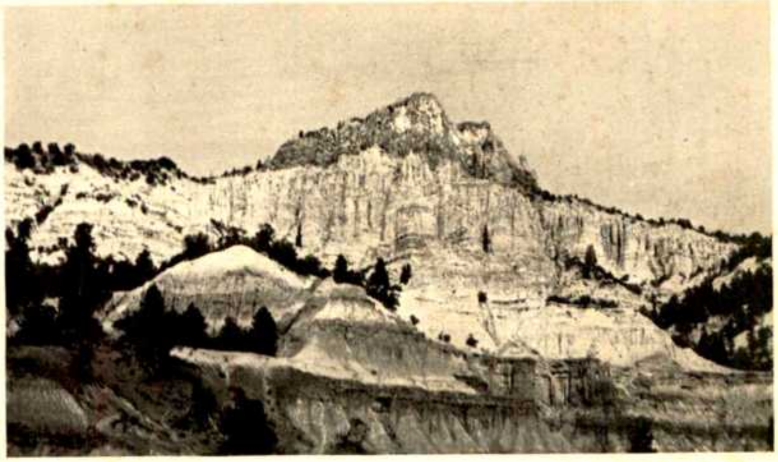

Plate 7. General view of the Brian Head formation at Hancock Bluff on the rim of the Sevier Plateau. Brightly colored stratified siliceous lime silts and pyroclastics are overlain by igneous conglomerates.

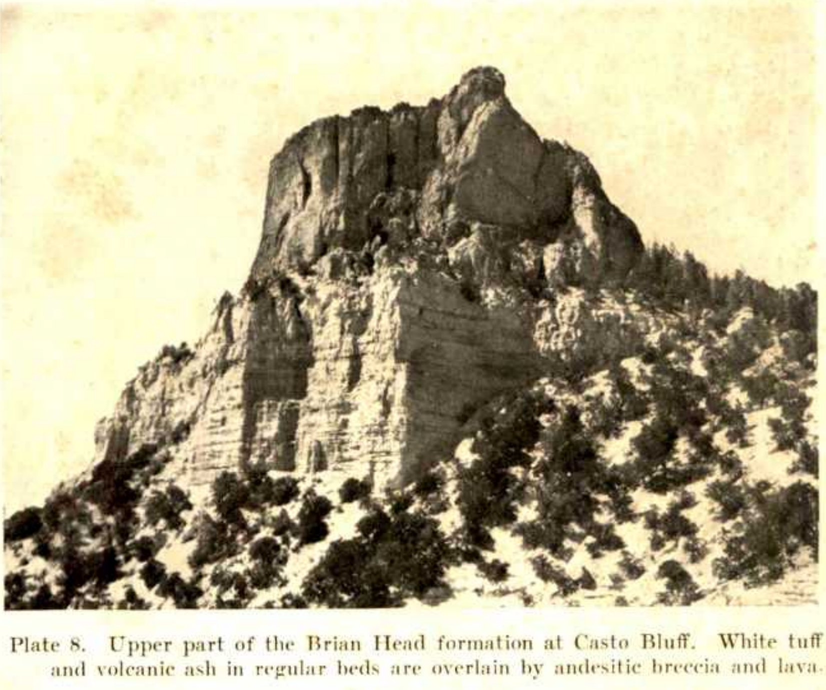

Plate 8. Upper part of the Brian Head formation at Casto Bluff. White tuff and volcanic ash in regular beds are overlain by andesitic breccia and lava.

Plate 9. Detailed view of the upper part of the Brian Head formation in Black Canyon along the East Fork of the Sevier River.

Plate 10. Detailed view of the lower part of the Brian Head formation in Limekiln Gulch. The thin-bedded, white, gray, and green pyroclastics and lenses of chalcedony are intricately eroded.

Examination of the Brian Head formation within the drainage basin of the upper Sevier River shows considerable variation in composition and arrangement of beds (see Pls. 4-10).

Along the southern rim of the Sevier Plateau and the western rim as far north as Sand Wash both the bedded lower part and the conglomeratic upper part of the formation are continuously exposed in the upthrown and in places the downthrown block of the Sevier fault. North of Sand Wash only conglomeratic rock is exposed, but in such thickness (500 to 1,000 + feet) and such intermingling of fine-grained, bedded, and massive rock as to give the impression that the two classes of sediments inter-grade and that finally the ash and tuffaceous deposits disappear. At Casto Bluff[13] and nearby headlands the lower part of the Brian Head formation is displayed as brightly colored slopes that weather in badlands fashion—mounds, grooved hillocks, rounded ridges, spires, and columns. As described by Norman C. Williams, Field Assistant,

> "it consists of four dominant types of water-marked sediments: (1) fine ash, (2) a mixture of sand, ash and products of disintegration of moderately crystalline volcanics, (3) pumice conglomerates, composed of well rounded pumice fragments ranging up to 4 inches in diameter embedded in a matrix of sand and ash, (4) stream and channel deposits consisting of conglomerates composed of well rounded quartzite, chert, and "rotten" rhyolite, granite and andesite pebbles; pure homogeneous sand, some of it crossbedded; exceedingly pure, thin clay lenses; and mudball conglomerates."

The black and white banded beds include lenses of magnetite and other heavy minerals, partly decomposed feldspar, conspicuous as white chunks. Some of the pink clays minutely interbedded with white ash resemble varves. The contact of the soft variegated Brian Head with the dense pink limestone characteristic of the Wasatch, though abrupt, appears to be gradational. A few feet below the contact the limestone includes thin lenses of green shale in which the dominant calcite is mingled with subangular quartz grains (10± per cent), feldspar, biotite, and limonite.

At the head of Petersen Canyon and in Limekiln Gulch the

[13] Casto Bluff and Casto Canyon were named for a pioneer settler, Abel N. Casto. On some maps the word is misspelled "Castro."

Brian Head consists chiefly of white, gray, and green, well-stratified, coarse "marls" but includes gray sandstone; lenses of well-worn quartz and quartzite pebbles; and thinly foliated beds sufficiently calcareous to justify quarrying for plaster. Chalcedony is abundant in strings, lumps, and beds as much as 4 feet thick and on weathering coats several acres with gray, blue, red translucent shards. The gray sandy beds contain bones and impressions of horny skin, probably of soft shell turtles. The green rock in Limekiln Gulch is described by Clarence S. Ross as

> composed dominantly of volcanic-rock minerals, among which plagioclase is dominant. This is associated with small amounts of hornblende, biotite, and magnetite. Detrital quartz in well-rounded grains, and fragments of limestone represent nonvolcanic materials which form around one-third of the rock. There is an almost total absence of potassic feldspars, and the plagioclase is calcic, some of it being sodic labradorite. The character of the feldspars indicates that these were derived from andesitic rocks, and this is confirmed by the presence of andesitic rock grains.
>
> A green, secondary material forms films around the mineral grains. Chemical tests show that this is a potassium mineral and this together with a moderately high birefringence, indicates that it is essentially similar to celadonite in composition.

In Sanford Canyon the oldest beds exposed are white siliceous shales (ash ?) that include long and short lenses 1 to 20 feet thick of the peculiar green rock displayed in Limekiln Gulch. Above this material lies several hundred feet of volcanic conglomerate and breccia, overlain in places by andesitic lavas. In the walls of Smith Canyon the dominant rock is a conglomerate of angular igneous boulders, many of them as much as 4 feet in diameter. Within the conglomerate are slabs and lenses of stratified ash and below it irregular beds of green white ash and tuffaceous material. The rocks in the canyon walls are arranged as blocks tilted in various directions along local (?) faults of undetermined trend and displacement. In Lost Creek Canyon south of Circleville the walls and adjoining areas consist wholly of conglomerate dominantly of angular, andesitic fragments, most of them 2 to 6 inches in diameter. Near the mouth of the canyon the conglomerate is finer-grained, some of it evenly bedded, and includes a few green pebbles.

Immediately along the East Fork of the Sevier the lower part

of the Brian Head formation is absent. Black Canyon is walled in by volcanic breccia that normally constitutes the upper part of the formation, and for about 4 miles below the mouth of Deer Creek this material is covered by lava flows. Farther north the overlying lava has been largely removed and the conglomerate forms the bench lands along the river and presumably lies beneath the alluvium about Antimony. In the walls of Black Canyon where 60 to 100 feet is exposed, the conglomerate is roughly bedded but very poorly sorted. It consists chiefly of wedge-shaped and slab-like fragments of igneous rock, 2 to 4 inches in diameter but contains some slabs as much as 4 feet long and considerable gravel-like material in which the larger fragments are embedded. The components of the igneous conglomerates are sharply angular and essentially unweathered; they resemble fragments freshly broken from dense massive lavas. This conglomeratic mass includes rare lenses of thin-bedded, medium-grained sandstone, but amygdaloidal and scoriaceous fragments, lapilli, and bombs appear to be absent. In thickness and in size and abundance of fragments the conglomerate in East Fork Valley seems to increase progressively westward and northward and thus suggests a source high on the northern Sevier Plateau, where, near the head of Sanford Canyon Dutton[14] noted "a brief exposure of what seems to have been an ancient trachytic vent and which is composed chiefly of cinders."

The Brian Head formation includes the oldest volcanics in the southern High Plateaus and though thick and widely extensive its source is unknown. No cinder cones or sheets of lava from which comparable material might have been derived are exposed along branches of the upper Sevier, and in adjacent regions the dikes in the Tertiary sediments pass entirely through the formation. Likewise, in the absence of diagnostic fossils or other conclusive evidence the age of the Brian Head formation is uncertain. Because it lies above the typical limestones of the Wasatch of late (?) Eocene age and, disregarding the lava flows below strata believed to represent the late Pliocene or early Pleistocene Sevier River formation, it seems reasonable tentatively to assign the Brian Head to the Miocene. The formation pre-dates the movements along the Paunsaugunt and Sevier faults in late Tertiary and early Quaternary times.

[14] Dutton, C. E.: op. cit., p. 77.

Petrography.

Selected rock specimens from the Brian Head formation were studied by Prof. Bronson Stringham, University of Utah, whose report is summarized as follows.

Rocks from the Western edge of the Sevier Plateau:

Mouth of Red Canyon. Limestone. Calcite 98 per cent; quartz fragments 2 per cent.

Losee Ridge. Acidic tuff. Clastic fragments of quartz, feldspar, hornblende, and glass.

Limekiln Gulch. Calcareous grit (tuff ?). Fragments in order of abundance: chalcedony, carbonate, quartz, feldspar, hornblende. Grains 1 mm. to 0.1 mm. in diameter, very irregularly shaped and angular. Cement of coarse calcite grains make up about 25 per cent of the rock.

Limekiln Gulch. Green sands. Clastic fragments in order of abundance: quartz, feldspar (andesine and labradorite), calcite and dolomite, quartz and feldspar aggregates, glass, lithic fragments of basalt and andesite, hornblende, magnetite, and kaolin. Fragments round to subround, 2 mm. to 0.05 mm. in diameter cemented by a green flaky to fibrous mineral identified as chlorite, var. clinoclore; chemical and optical tests distinguish it from vivianito, glauconite, celadonite, chamosite, and greenalite.

Sanford Canyon. Igneous conglomerate. Fragments of andesite and basalt of usual composition.

Smith Canyon. Igneous conglomerate. Lithic andesite and basalt fragments and porphyritic crystals. Grains in groundmass 1-3 mm. in diameter.

Smith Canyon. Vitric crystal tuff. The 7 specimens from lenses in igneous conglomerate are dark to light green in color and contain quartz, feldspar, hornblende, biotite, acidic glass with shards, and other minerals characteristic of igneous rocks. Green color due to numerous shreds of chlorite, which constitutes the cement. Closely similar to "green sands" in Limekiln Gulch.

Rocks from the Western edge of the Aquarius Plateau:

Sweetwater Canyon. Limestone. Calcite 98 per cent;

quartz fragments of various sizes and a little colloform chalcedony.

Birch Creek. Limestone. Chiefly calcite (90 + per cent), and angular fragments of quartz. [This rock closely resembles the calcareous silt in nearby Horse Canyon, analyzed in Section 2.]

Cleaves Gulch. Consolidated ash. Contains quartz, orthoclase, plagioclase, biotite, glass, and chalcedony. Glass in shreds, rods, and shard-shaped bodies.

Black Canyon. Igneous conglomerate. Chiefly coarse and fine-grained andesite and basalt boulders; includes hornblende crystals and black vitrophyre.

The laboratory study of thin sections of rock considered typical of the Brian Head formation supports the field observations that on the Paunsaugunt and the southern Aquarius plateaus the lower part of the Brian Head formation consists almost wholly of calcite and that northward the relative amount of clear quartz and of chalcedony increases and the pyroclastics become more and more prominent. However, the change from dominant limestone to dominant tuff is not regularly progessive. In places the pyroclastics include calcareous silts and in other places chunks of chalcedony and rotted andesite appear in outcrops composed essentially of thin-bedded limestone.

SEVIER RIVER FORMATION *(Pliocene or Pleistocene).*

Rocks doubtfully correlated with the Sevier River formation outcrop in small areas on the Aquarius Plateau and along the South Fork of the Sevier River and its tributaries. Characteristically they are partly consolidated gray boulder conglomerates lenticularly interbedded with gray, tan, and black sandstones. As exposed along Highway 89, south of Panguitch they include basaltic and andesitic conglomerates containing boulders as much as 2 feet in diameter, fine-grained volcanic débris, clay, silt, and scattered pebbles of chert and chalcedony. The material obviously was deposited by streams flowing in poorly defined channels and subject to wide fluctuation. The outcrops show the texture, the style of bedding, and the vertical and lateral unconformities that characterize fanglomerates of local origin, accumulated in local basins (see Pl. 11).

PLEISTOCENE AND RECENT SEDIMENTS.

On the Aquarius Plateau glacial till, in some valleys kames, rest on the lavas and ice-borne débris borders several lakes. Near the mouths of Casto and Red Creeks stratified drift that contains Pleistocene fossils is exposed beneath alluvium and talus. In the banks of Casto Creek 60 + feet of glacial sediments are sufficiently consolidated to permit erosion by spalling. The predominant material is dark-gray, compact sandy clay in roughly shaped beds 1 to 8 feet thick; subordinate materials are marls and coarse gravel. The marl, in places chalklike and interbedded with ash, siliceous silts, and ash (?), forms white layers 6 to 20 inches thick and continues for at least 200 feet. The gravel, which consists chiefly of irregularly shaped, little worn igneous fragments 1/8 to 1/2 inch in diameter, is distributed as lenses—thicker, more numerous, and coarser toward the top of the deposit.

In consequence of erosion during Recent times most of the streams are cutting deeply into the valley fill laid down during a previous cycle of aggradation.

In late Pliocene and Recent times the rock-floored canyons were partly filled with alluvial and, locally, lacustrine deposits, which, in consequence of a change in stream habit from aggradation to degradation, is now in process of removal. Generally along the Sevier River and its tributaries the once continuous flat expanses of stratified sand and gravel have been cut into terraces. During the past half century the intricate dissection of the fill has caused the relocation of roads and the abandonment of much farm land (see Pl. 12).

STRATIGRAPHIC SECTIONS.

1. Section in Antimony Canyon.

Composite of 4 sections measured within an area of about a square mile.

	Feet
16. Alluvial sand and gravels in terraces bordering streams; talus and landslide debris on slopes..........................	0–100
Unconformity	
15. Basalt, thin sheet, covering small areas on the Aquarius Plateau.	
Unconformity	
14. Sevier River (?) formation. [Recorded by D. C. Duncan]. Gray boulder conglomerate interbedded with salmon pink sandstone. Conglomerate consists of volcanic boulders in angular sand matrix. Unit poorly consolidated, weathers in low banded cliffs and steep slopes, estimated..........	600

Unconformity	
13. Andesite (?), dense and porphyritic, in overlapping flows 2 to 6 feet thick; includes irregular masses of igneous agglomerate and of massive, amygdaloidal and scoriaceous lava. Stands as a wall about the headwater branches of Antimony Canyon and southward forms the surface of Aquarius Plateau. At the mouth of the canyon, on the downthrown block of the Paunsaugunt fault, remnant masses weather into knolls. Maximum thickness, estimated	1000
Unconformity	
Brian Head formation	
12. Volcanic conglomerate: chiefly angular fragments of acidic lava: contains some blocks of sandstone and scattered quartzite pebbles	0–80+
Unconformity	
Tropic formation	
11. Shale and sandstone, lower part faintly banded gray brown, buff, and drab; upper half dominantly gray green and tan; arenaceous and argillaceous, rare gypsiferous and carbonaceous shales in groups 2 to 100 feet thick overlap or replace along strike massive, thick bedded, and thin bedded sandstone 1 to 40+ feet thick; includes lenticular masses of limestone, concretionary nodules of iron, lenses and veinlets of stibnite, and near the top a thin bed of bentonite; the calcareous sandstones contain fragmentary fossils; weather as steep slopes broken by narrow projecting ledges of limestone of concretionary iron	860–1180
Dakota (?) sandstone	
10. Conglomerate and sandstone, gray and tan; commonly roughly bedded, coarse sandstone with scattering pebbles; locally a mass of well worn quartzite and limestone pebbles, ¼ to 2 inches in diameter and angular slabs of sandstone embedded in a calcareous and siliceous matrix; grades into No. 11	10–180
Dakota (?) sandstone	
Unconformity	
Curtis and Winsor formations, undifferentiated	
9. Sandstone, gray, highly calcareous; irregular, lumpy beds 1 inch to 1 foot thick. fragmentary fossils; relatively resistant, forms cliff and bench above, varies much in thickness and along strike, in places is absent	6–35
8. Shales, yellow gray, sandy, slightly gypsiferous; irregularly alternating and lenticular, even bedded. Forms steep slope	42
7. Shales and subordinate thin sandstones; roughly banded, yellow gray, green gray, white, and light red; includes gypsum in thin irregular seams and disseminated grains; includes near the middle hard thin bedded limestone as much as 10 feet thick and at the top subangular pebbles of varicolored quartzite, white quartz, hard limestone, and clay balls, 1/16 to 1 inch in diameter, embedded in a dark gray calcareous sand	88
Total Curtis and Winsor formations	165±

Unconformity (?)	
Entrada sandstone	
6. Sandstone, deep red, streaked with white, even bedded, in places shaly; well rounded, fine grains of quartz cemented by lime and iron; slightly gypsiferous; generally at the base and locally higher up includes yellow-white bands and lenses of well worn pebbles of quartzite, quartz, and limestone. Weathers as steep slopes and cliffs marked by grooves, pilasters, columns, and detached towers; generally top beds hardened to form shelves and projecting ledges	180–220
Unconformity ?	
Carmel formation	
5. Limestone, gray, blue gray on fresh fractures; very thin bedded, even bedded; dense, brittle, in places friable; weathers into hard, angular chips. At the base and top, brown and greenish, sandy, calcareous shales; surface of some beds show ripple marks, worn trails, and lumpy aggregates (algae ?); marine fossils. Stands nearly vertical against Navajo sandstone; weathers into dikelike ridges and grooves	460
Unconformity	
Navajo sandstone	
4. Sandstone, light gray, in places tan, generally massive except for units outlined by widely spaced indistinct bedding planes, in part cross bedded; composed of very fine spherical glistening grains of quartz; intricately fractured and faulted on a small scale both along and across strike; stands nearly vertical. Average thickness estimated	1100
Unconformity: fault plane	
Chinle (?) formation: Curtis (?) and Winsor (?) formations	
3. Shale, green, ash gray, rarely pink or white; argillaceous, arenaceous, and gypsiferous; very friable; dips westward; separated from No. 4 by a fault. Nos. 2 and 3 are generally concealed by coarse gravel	50
2. Shale and thin irregularly bedded sandstone, deep red, in places tan; includes tiny flakes and lenses of drab, gypsiferous, compact clay; dips steeply west to a fault, contact with acidic lavas	180
Unconformity ? fault plane ?	
Shinarump (?) conglomerate	
1. Conglomerate, gray, lenticularly stratified and cross bedded; pebbles chiefly quartzite, quartz, and rare hard, black limestone, well rounded, some polished, the largest pebbles as much as 5 inches in diameter; includes lenses of sandstone; matrix of siliceous sand and gravel in which are tiny fragments of metamorphic and igneous (?) rock	20–60
Total thickness	4586–5829

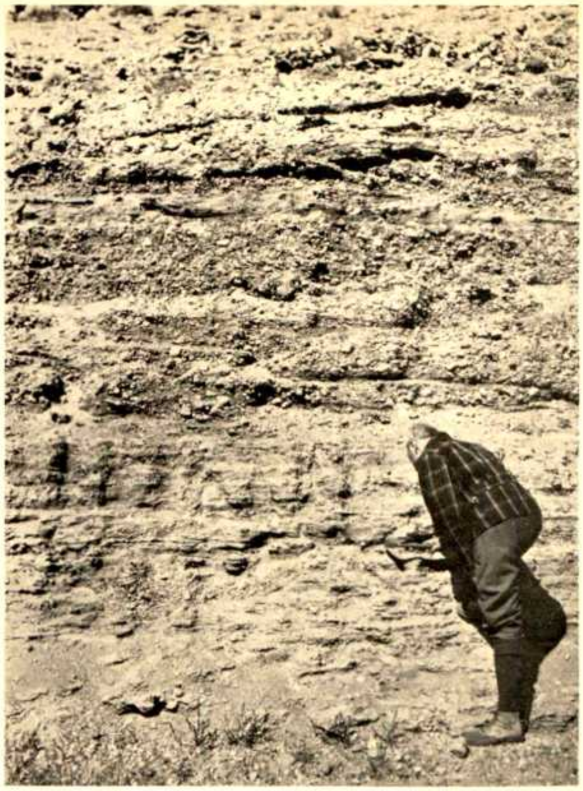

Plate 11. Characteristic exposure of the Sevier River (?) formation along Federal highway 89 south of Panguitch.

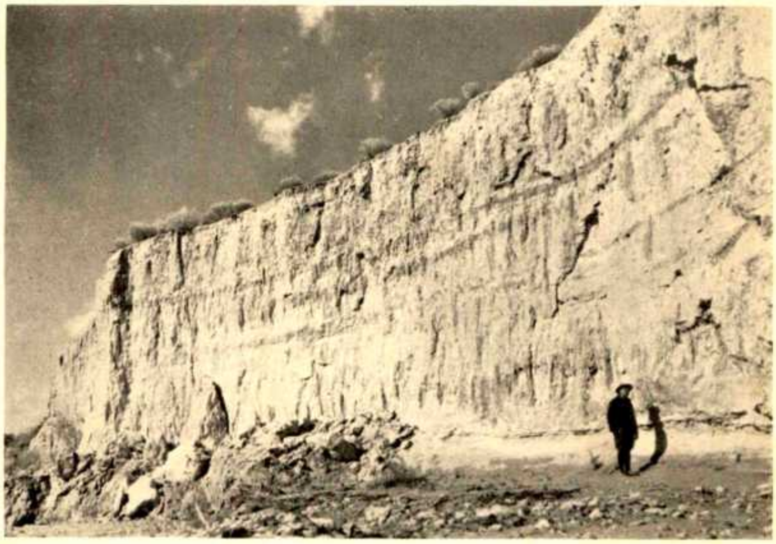

Plate 12. Bank of Red Creek below the mouth of Red Canyon. Wall of Recent alluvium rests unconformably on fossiliferous marls of

2. Section in Horse Creek Canyon.

	Feet
4. Andesite (?) in sheets and lumpy masses of igneous conglomerate; forms a bench between faults (?) on the west flank of Aquarius Plateau; thickness estimated	600
Brian Head formation	
3. Igneous agglomerate. Bouders of dense and scoriaceous lavas; largely concealed by talus from No. 4. Thickness estimated	400
2. Shales, white, calcareous and siliceous, mainly amorphous consolidated silt; regularly stratified in beds 2 to 4 inches thick; resistant beds form projecting ledge near the top and little shelves and mesas on an otherwise nearly vertical cliff; slopes coated with glistening white powder which are small fragments of chalcedony	120
Total Brian Head formation	520
Wasatch formation	
1. Limestone, pink and light red; generally in thick, massive, poorly defined beds; fairly well stratified near the top; includes thin, hard, porous layers concentrically overlapping as in travertine; near the base lenses of gray conglomerate—small rounded pebbles of quartzite and quartz embedded in calcareous material; forms nearly vertical cliff carved into pinnacles; part exposed	520
Total thickness measured	1640

3. Section in Cleaves Gulch near "Burro Flat," 4+Miles South of Center Creek.

	Feet
4. Andesite porphyry?, megascopic crystals of orthoclase in a groundmass of feldspar and quartz; basal 6 feet red and black sheets, 2 to 5 inches thick, extremely dense, some of it glassy. Forms top of fault block on the lower west flank of Aquarius Plateau; largely destroyed by erosion	260
Unconformity	
Brian Head formation	
3. Conglomerate, unstratified, composed of angular igneous pebbles, the largest as much as 4 feet in diameter; groundmass of igneous gravel and sand. Forms nearly vertical cliff	86
Unconformity	
2. Limestone, siliceous, dark gray near base, white above; fairly regular beds 3 inches to 3 feet thick; includes chalcedony in thin sheets and lenses. Forms steep uneven slope	130
Total Brian Head formation	216
Unconformity	
Wasatch formation	
1. Limestone, pink, massive, sandy, includes lenses of calcareous	

clay shales stratified like lacustrian silts; largely concealed by debris from landslides and dissected alluvial fans; part exposed	70
Total thickness measured	546

4. Section in North Branch of Limekiln Gulch.

	Feet
Brian Head formation	
7. Volcanic breccia; part exposed estimated	200+
6. Calcareous and siliceous shale, volcanic ash, travertine, and fine-grained sandstone, indistinctly banded pink, white, and yellow; regular beds; much chalcedony in thin slabs 1 to 4 feet in diameter; weathers as hard surfaced, steep slope...	84
5. Sandstone, green, coarse grained; in 5 fairly regular groups of beds 1 to 5 feet thick, hard enough to form cliffs that weather into knobs and columns; contains small pebbles of quartz, quartzite, and igneous rock, isolated and in strings; at base irregular lenses 1 to 5 inches thick, 10 to 50 feet long of gray hard, siliceous limestones; in the green sand the microscope reveals hornblende, magnetite, kaolin, glass, andesane, labradorite, calcite, dolomite, and subrounded fragments of basalt and andesite .05 to 2 mm. in diameter cemented by a fibrous green mineral—chlorite (?), celadonite (?)	26
4. Shale, along strike and in sequence various shades of green, yellow, brown, and gray; essentially sandy clay and ash; fine grained regular beds; very friable except for tightly cemented lozenges and discs that weather as knobs and caps of pinnacles. At 22 feet above the base thin band of rusty pink limestone and at 42 feet a thin black band composed chiefly of magnetite grains. An intricately dissected slope	180
3. Shale, green, sandy, interbedded with impure limestones; includes lenses of conglomerate and sandstone, much chalcedony including near the base a lenticular mass 2 to 2¾ feet thick and 100+ feet long; forms a steep slope dissected into mounds and gullies	286
2. Limestone, white, siliceous, thin bedded, includes much conglomerate with calcareous matrix composed of subangular pebbles of black and white quartz, variegated quartzite, black limestone, and dense igneous rock fragments, some as much as 2 inches in diameter	92
1. Red conglomerate	67
Total Brian Head formation	968

Wasatch formation; compact pink limestone

In this section units 1-3 were measured by J. C. Anderson on the upthrown side of the Sevier fault at the base of Blind Spring Peak, about 2 miles northeast of Nos. 4-7; probably duplicates in part unit 4, incompletely exposed in the downthrown block.

EXTRUSIVE IGNEOUS ROCKS.

Within the drainage basin of the upper Sevier River andesites and closely related lavas are displayed as extensive, more or less continuous sheets on the top of the Aquarius Plateau, and on the Sevier Plateau they are irregularly distributed over the volcanic breccia which forms the general surface. The field relations suggest that these rocks represent lavas that were extruded during one general period of volcanic activity and not long after the volcanic breccia in the Brian Head formation was laid down. Basalts of younger age occupy small areas in various topographic positions and came from local vents. All the lava sheets are older than the major faults. The composition of the lavas is shown by the following descriptions of specimens thought to represent the most common varieties within the region under review. Farther north casual traverses reveal a greater variety of rock type and much more complex interrelations.

1. Mouth of Red Canyon. Olivine basalt. Well shaped phenocrysts of olivine and labradorite in lattice-like groundmass of labradorite. Crowded between the laths are grains of augite and magnetite. In part vesicular.

2. Mouth of Red Canyon. Hornblende basalt. Minerals in order of abundance: labradorite in small crystals and phenocrysts, augite, hornblende, glass, and magnetite. Shows small-scale vesicular structure.

3. Losee Ridge. Basalt. Microscopic crystals of labradorite, augite, magnetite, and subordinate glass. In one thin section the structure is vesicular, in another compact.

4. Outlier of Sevier Plateau; North branch of Casto Canyon. Andesite. Contains andesine, augite, and magnetite crystals, many of them surrounded by glass. Andesine crystals, submicroscopic to 2 mm. in diameter constitute the bulk of the rock. Probably represents in general the lava cap of parts of the Sevier Plateau.

5. South branch of Peterson Wash. Andesite porphyry. Large and small crystals of andesine, prominently zoned and variously oriented; unaltered augite (or diopside), and phenocrysts of light, broad, beautiful pleocroic hornblende. Groundmass contains much magnetite, some isotropic material (glass?) and patches of green chlorite that may represent biotite.

6. Black Canyon near Osiris. Andesite porphyry. In hand

specimens a very dense, light-purple rock criss-crossed with short white laths. Microscope reveals phenocrysts of andesine in a ground mass of crystals of submicroscopic size.

7. Aquarius Plateau near head of Antimony Creek. Basalt. Minerals content: olivine phenocrysts, about 10 per cent, augite 5 per cent, magnetite 2 per cent, and basic turbid glass. The labradorites, which constitute 90 per cent of the feldspar crystals, range in size from phenocrysts 3 mm. in length to microscopic fragments and are more or less tabular in form. Their molecular composition is $Ab_{45}An_{55}$. The larger crystals are zoned and material of the outer rim is close to albite in composition. A little opal is present in vugs. This rock, collected as representative of the extensive lava sheets on the Aquarius Plateau, may be part of local extrusion. Dutton states that the rocks on the Aquarius are "chiefly hornblendic trachytes commingled with very extensive masses of augitic andesites."

STRUCTURE.

The major structural features of the upper Sevier valleys are the Paunsaugunt fault, which marks the west base of the Aquarius Plateau, and the Sevier fault, which lies along the west base of the Sevier Plateau. The main Paunsaugunt fault lies in a zone of faulting that extends southward across Utah and into Arizona and northward along the base of the Awapa Plateau—the Grass Valley fault of Dutton. The Sevier fault, which also extends far southward and northward, is in most places represented by a single escarpment and a narrow belt of displaced rock.

The position and the effect of the Paunsaugunt fault zone is revealed in the topography and the attitude of the lavas and underlying sediments. Toward the fault the lavas and the underlying igneous conglomerates that cap the Sevier Plateau dip eastward to their termination in the East Fork Valley, where remnants stand as inclined blocks. East of the fault the corresponding lavas and pyroclastics form the surface of the Aquarius Plateau, at altitudes of 10,000 to 11,000+ feet. Thus the height of the Aquarius Plateau—about 3,500 feet above its westward bordering lowlands—measures the movements within a zone of fracture which here consists of three or more roughly parallel faults that give to the west flank of the plateau the appearance of a series of giant steps. The west-

ernmost of these faults forms the eastern wall of Black Canyon between Osiris and the mouth of Deer Creek and for a few miles south is marked by tilted and fractured blocks through which the East Fork of the Sevier finds its way. North of Osiris the fault continues across Center and Poison creeks where, in the upthrown block, cliffs of pyroclastics and lava are about 2,000 feet high. At Antimony Creek the major displacement is estimated to be 1,800 feet; it has raised the Jurassic strata to the level of the Tertiary volcanic conglomerate. A second long fault marks the base of the escarpment at the heads of Birch, Ranch and Center creeks, and a third is assumed to mark the position of the high cliff-bound tables near the plateau top (see Fig. 2). In addition to these major displacements, expressed in the regional topography, faults with throws of 130, 250, and 400 feet cut the walls of Antimony Canyon; movements of similar amounts doubtless have occurred elsewhere along the western edge of the Aquarius Plateau. Faults with throws of 2 to 10 feet, slickensided fractures, and belts of crushed rock, are fairly common, especially along lines of closely spaced jointing.

The Sevier fault is marked by discordance of strata associated with abrupt termination of color bands and, in distant views, by rock terraces which outline the upthrown and downthrown blocks. Its position and its salient features are plainly revealed in the great canyons that score the west face of the Sevier Plateau. Crossing the mouths of Red and Casto Canyons the fault-line scarp developed in Wasatch formation is a vertical wall 100 to 500 feet high. Farther north in Petersen Wash and Limekiln Gulch the pink limestone of the Wasatch abuts against the white tuffaceous material and the conglomerates of the Brian Head formation—in places against lavas—and in association with the major fault, minor parallel and oblique faults cut the sediments into blocks variously orientated; some dip east against the main fault plane, some southeast or southwest. The Sevier fault, as pointed out by Gilbert,[15] lies within a very narrow zone of disturbance; in places it is a single fracture. Disregarding the effect of the slight eastward dip of adjacent strata, the stratigraphic displacement effected by the fault east of Panguitch is estimated to be 1,000 feet;

[15] Gilbert, G. K.: 1875, Geog. Geol. Expl. and Surveys W. 100th Mer., vol. 3, p. 49.

the severed parts of once continuous masses of igneous rock remain at altitudes of approximately 7,000 and 8,000 feet.

For about 100 miles north of the Grand Canyon of the Colorado the Paunsaugunt and Sevier fauts are roughly parallel, nearly vertical, and essentially single displacements, but in the vicinity of Widtsoe and Panguitch these simple structures lose their identity. Especially in the downthrown blocks numerous faults replace single features, and north of Circleville Canyon the fault patterns become remarkably complex. It is interesting to note that this radical change in the character and distribution of fractures within the Sevier fault zone —more characteristic of the Great Basin Province than of the Colorado plateaus—is substantially duplicated at Kanarraville and Cedar City, where the Hurricane fault fans out into many faults of various displacements and alinement, among which the master fault is difficult to place.

In the absence of established time markers, the date of faulting in the upper Sevier Valley can be fixed only approximately. The Paunsaugunt and the Sevier faults have broken all the Tertiary sediments, pyroclastics, and lavas, and most of the smaller faults traverse several formations, but the pressure that produced them may have been exerted at any time or at several times since regional uplift created the present High Plateaus. The great erosion that has remodeled the upthrown blocks and covered the downthrown blocks with alluvium, in places fully 800 feet thick, is evidence of long lapses of time. On the other hand, some of the movements have been so recent as to leave fault scarp almost intact.

The structural, stratigraphic, and physiographic evidence seems sufficient to prove that the movements within the major and some of the minor fault zones in the Upper Sevier Valley were recurrent rather than contemporaneous; and that the forces that uplifted the Sevier and Paunsaugunt Plateaus to their present great height operated intermittently. Satisfactory interpretation of the geologic history of the Upper Sevier valleys involves the assumption that structural disturbances began in late (?) Tertiary time and are still in progress.

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NOTES ON THE CRETACEOUS SPECIES DESCRIBED BY KARRER.

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ABSTRACT. The new species described by Karrer in 1870 from the Cretaceous of Austria were studied in Vienna. The actual specimens were redrawn and notes made as to the validity of the species.

IN 1870 Karrer described a foraminiferal fauna from the Cretaceous of Austria: "Ueber ein neues Vorkommen von oberer Kreideformation in Leitzersdorf bei Stockerau, und deren Foraminiferenfauna" (Jahrbuche der k. k. geologischen Reichsanstalt, vol. 20, 1870, pp. 157-184, pls. 10, 11). Many of the species are referred to those described earlier by d'Orbigny, Reuss, and others, but thirty species are described as new. As some of our American Cretaceous species resembled the figures given by Karrer, I made a study of the type specimens in Vienna in the summer of 1932. Although the type specimens were not in all cases segregated, it was possible to determine which were the figured ones. It was at once apparent that, as in many other papers, the illustrations were more or less conventionalized and in some cases were misleading. For future reference notes were made on these types and nearly all of them were redrawn from the original types. As some of the species names have been used in connection with our American Cretaceous forms and others are closely allied to them it seems worthwhile to present these notes and drawings that they may be available to American workers on the foraminifera.

Gaudryina cretacea (Karrer) (Pl. 1, fig. 1).

Verneuilina cretacea Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 164, pl. 10, fig. 1.

Gaudryina rugosa Karrer (not d'Orbigny), l. c., p. 166.—Egger, Abhandl. kön. bay. Akad. Wiss. München, Cl. II, vol. 21, 1899, p. 37, pl. 4, figs. 14, 15.

Gaudryina cretacea Cushman, Special Publ. No. 7, Cushman Lab. Foram. Res., 1937, p. 40, pl. 6, figs. 3-9.

The type, here refigured, is the young triserial stage. The Karrer collection shows adults also that he referred to *G. rugosa* d'Orbigny but they are not the same as d'Orbigny's species. The species is common and widely distributed in the

Upper Cretaceous of Central Europe but apparently does not occur in the American Cretaceous.

Textularia roscida (Karrer) (Pl. 1, figs. 2, 3).

Plecanium roscidum Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 165, pl. 10, fig. 2.
Plecanium foedum Karrer, l. c., p. 165, pl. 10, fig. 3.

A specimen nearest in shape to the original figure was selected and drawn. It seems to be truly biserial with a very coarse exterior and the sutures are not nearly as definite as in the original figure. Karrer's *P. foedum*, from an examination of the type series, is a young stage of *Textularia roscida.* The species apparently does not occur in the American Cretaceous.

Dorothia crassa (Karrer) (Pl. 1, fig. 4).

Gaudryina crassa Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 166, pl. 10, fig. 4.
Dorothia crassa Cushman, Special Publ. No. 8, Cushman Lab. Foram. Res., 1937, p. 84, pl. 10, fig. 17.

Most of the specimens in the Karrer collection in Vienna are crushed and somewhat distorted. The surface is smooth and the species is evidently a *Dorothia*, related to *D. pupa* (Reuss) and possibly identical. It is related to *D. bulletta* (Carsey) of the American Cretaceous but is distinct.

Triloculina vitrea Karrer (Pl. 1, fig. 7).

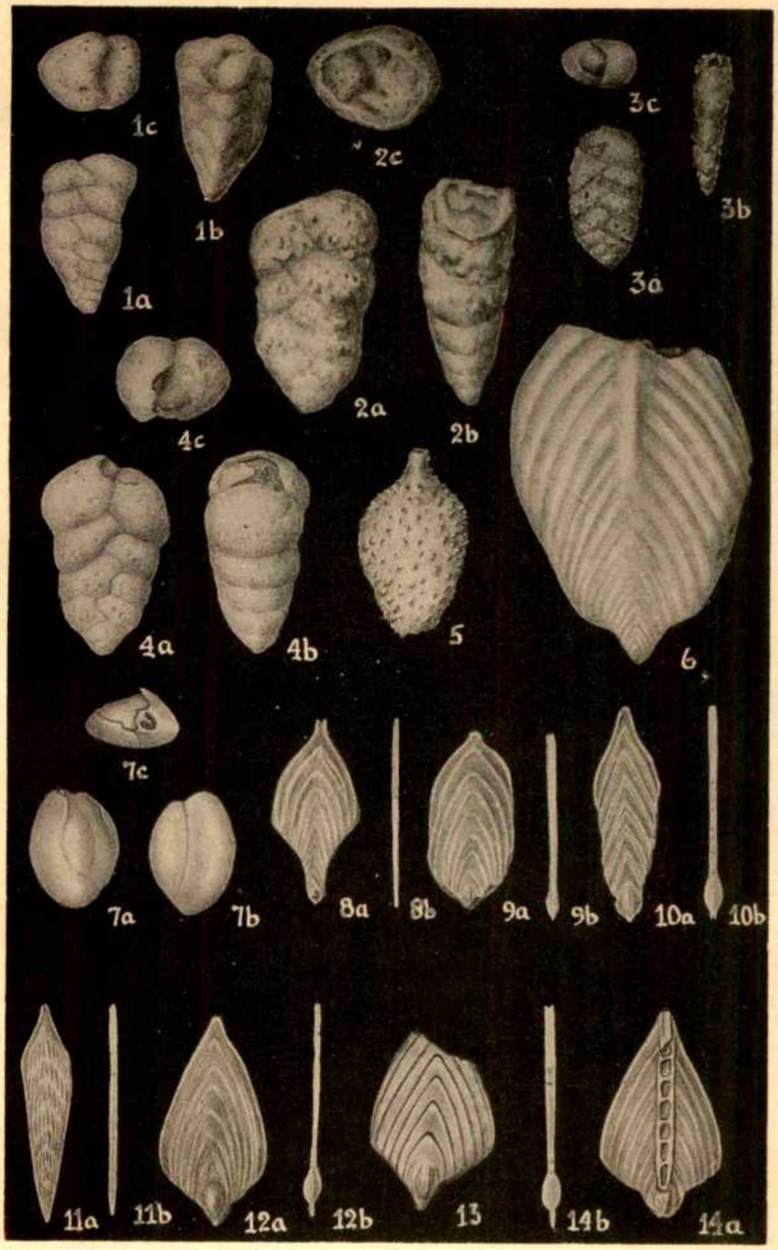
Triloculina vitrea Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 167, pl. 10, fig. 5.

EXPLANATION OF PLATE 1.

(Unless otherwise noted, *a*, front view; *b*, side view; *c*, apertural view.)

Fig. 1. *Gaudryina cretacea* (Karrer). "*Verneuilina cretacea* Karrer."
Figs. 2, 3. *Textularia roscida* (Karrer). 2, "*Plecanium roscidum* Karrer." 3, "*Plecanium foedum* Karrer."
Fig. 4. *Dorothia crassa* (Karrer). "*Gaudryina crassa* Karrer."
Fig. 5. *Ramulina aculeata* (d'Orbigny)?. "*Lagena tuberculata* Karrer."
Fig. 6. *Frondicularia leitzendorfensis* Karrer.
Fig. 7. *Triloculina vitrea* Karrer. *a*, *b*, opposite sides; *c*, apertural view.
Fig. 8. *Frondicularia pulchella* Karrer.
Fig. 9. *Frondicularia felis* Karrer.
Fig. 10. *Frondicularia amoena* Karrer.
Fig. 11. *Frondicularia pala* Karrer.
Figs. 12-14. *Frondicularia goldfussi* Reuss. 12, "*Frondicularia Althii* Karrer." 13, 14, "*Frondicularia sarissa* Karrer." 14, showing broken portions of freak specimen.

All figures redrawn from original specimens in Museum in Vienna.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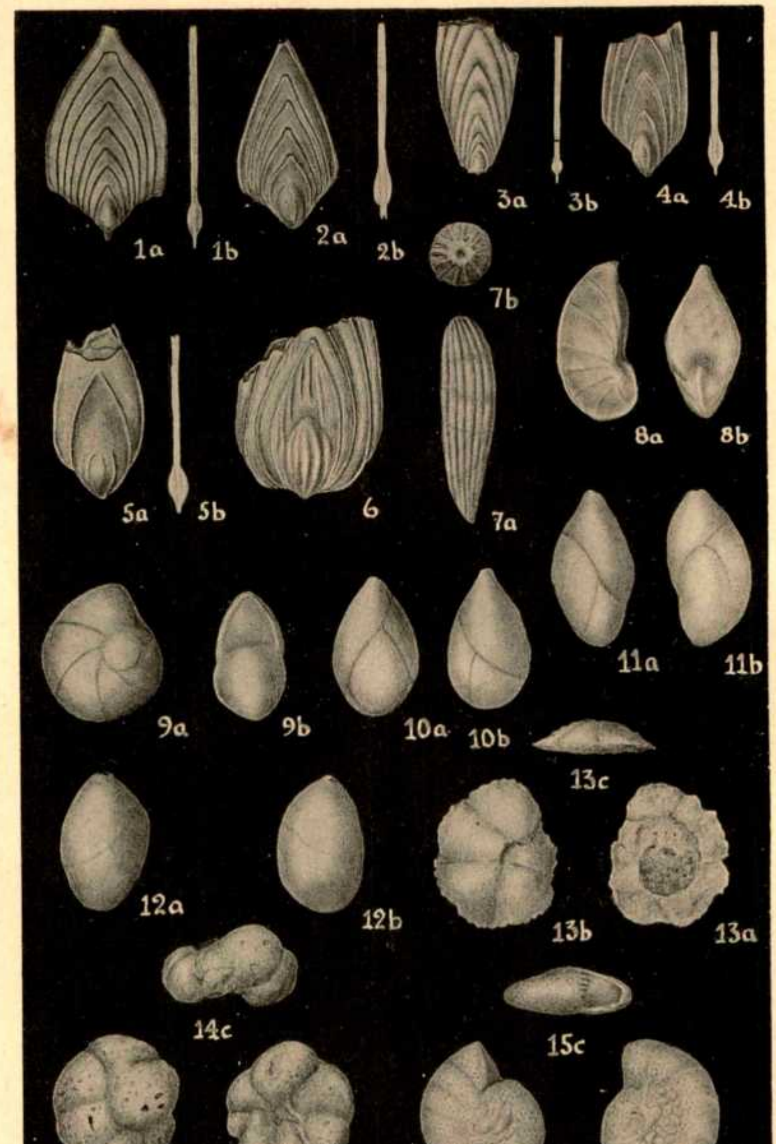
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The type is redrawn on our plate. The end view is much more rounded than in the original figure. The genus is very rare in the Cretaceous. In the American Cretaceous, specimens referred to *T. circularis* Bornemann are more like this species of Karrer. They seem to be limited to the Ripley formation of Tennessee.

Ramulina aculeata (d'Orbigny)? (Pl. 1, fig. 5).

Lagena tuberculata Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 168, pl. 10, fig. 6.

The type figure is evidently conventionalized. The specimens are all somewhat compressed and represent a species of *Ramulina* close to or identical with that of d'Orbigny's. Somewhat similar specimens occur in our American Cretaceous and have been referred to d'Orbigny's species.

EXPLANATION OF PLATE 2.

Figs. 1, 2. *Frondicularia goldfussi* Reuss. 1, "*Frondicularia plana* Karrer." 2, "*Frondicularia Fuchsii* Karrer." *a, a,* front views. *b, b,* side views.

Figs. 3-5. *Frondicularia fragilis* Karrer. 4, "*Frondicularia pyrum* Karrer." 5, "*Frondicularia tribus* Karrer." *a, a, a,* front views; *b, b, b,* side views.

Fig. 6. *Frondicularia speciosa* Karrer.

Fig. 7. *Marginulina crassicostata* Karrer. *a,* front view; *b,* apertural view.

Fig. 8. *Saracenaria sinus* (Karrer). "*Cristellaria sinus* Karrer." *a,* side view. *b,* front view.

Fig. 9. *Robulus tumidus* (Karrer). "*Cristellaria tumida* Karrer." *a,* side view; *b,* front view.

Fig. 10. *Globulina lacrima* Reuss. "*Polymorphina longicollis* Karrer." *a, b,* opposite sides.

Fig. 11. *Globulina gravis* (Karrer). "*Polymorphina gravis* Karrer." *a, b,* opposite sides.

Fig. 12. *Globulina ampla* (Karrer). "*Polymorphina ampla* Karrer." *a, b,* opposite sides.

Fig. 13. "*Truncatulina horrida* Karrer." *a,* dorsal view; *b,* ventral view; *c,* peripheral view.

Fig. 14. *Cibicides danubius* (Karrer). "*Discorbina Danubia* Karrer." *a,* dorsal view; *b,* ventral view; *c,* peripheral view.

Fig. 15. *Anomalina fontana* (Karrer). "*Rotalia fontana* Karrer." *a,* dorsal view; *b,* ventral view; *c,* peripheral view.

All figures redrawn from original specimens in Museum in Vienna.

Frondicularia leitzendorfensis Karrer (Pl. 1, fig. 6).

Frondicularia Leitzendorfensis Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 171, pl. 10, fig. 7.

This is a large species with a peculiar shape and a thickening along the median line especially in the later portion. Some of the specimens are as much as 6 mm. in length. There are forms in the American Cretaceous apparently identical with this, recorded by Bagg from the Cretaceous of New Jersey as *Frondicularia ovata* Roemer (Bull. 88, U. S. Geol. Survey, 1898, p. 49, pl. 4, fig. 2).

Frondicularia pulchella Karrer (Pl. 1, fig. 8).

Frondicularia pulchella Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 171, pl. 10, fig. 8.

The holotype is the only specimen in the Karrer collection. It is not depressed in the middle as the original figure indicates. It may be a freak form of some of the other described species.

Frondicularia felis Karrer (Pl. 1, fig. 9).

Frondicularia felis Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 172, pl. 10, fig. 9.

This species, as shown by the types, is about half the size of *F. leitzendorfensis* Karrer and is probably a young stage of that species.

Frondicularia amoena Karrer (Pl. 1, fig. 10).

Frondicularia amoena Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 172, pl. 10, fig. 10.
Frondicularia Stachei Karrer, l. c., p. 174, pl. 11, fig. 2.

These two probably represent a single species. The type of *F. stachei* is about half the size of the type of *F. amoena* and is evidently a young stage. Both forms probably come under the range of *F. archiaciana* d'Orbigny.

Frondicularia pala Karrer (Pl. 1, fig. 11).

Frondicularia pala Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 172, pl. 10, fig. 11.

The holotype seems to be the only specimen in the Karrer collection. He mentions that it is very rare. The original figure is much conventionalized and it was redrawn for our plate. It is somewhat like *F. angusta* Nilsson but more specimens are needed to make sure of its full characters.

Frondicularia goldfussi Reuss (Pl. 1, figs. 12-14; pl. 2, figs. 1, 2).

Frondicularia Althii Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 172, pl. 10, fig. 12.
Frondicularia sarissa Karrer, l. c., p. 173, pl. 10, fig. 13.
Frondicularia plana Karrer, l. c., p. 174, pl. 10, fig. 14.
Frondicularia Fuchsii Karrer, l. c., p. 174, pl. 11, fig. 1.

From a study of the series of type specimens these four seem to belong to one species. All probably may be included under *F. goldfussi* Reuss which Karrer also records from this same locality. The specimens are more alike than the original figures indicate. For example, the original figure of *F. althii* gives the appearance of being excavated but the specimen does not show this character. They are very close to the figure given by Reuss of *F. filocincta* (Sitz. Akad. Wiss. Wien, vol. 46, pt. 1, 1862 (1863), p. 54, pl. 4, fig. 12) from the Cretaceous of North Germany but not referred to later.

Frondicularia fragilis Karrer (Pl. 2, figs. 3-5).

Frondicularia fragilis Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 175, pl. 11, fig. 3.
Frondicularia pyrum Karrer, l. c., p. 175, pl. 11, fig. 4.
Frondicularia tribus Karrer, l. c., p. 175, pl. 11, fig. 5.

From the original figures these would not seem to be related but the specimens show they are very similar and probably represent stages of megalospheric specimens in which the size of the proloculum differs. It is difficult to refer these to any previously described species.

Frondicularia speciosa Karrer (Pl. 2, fig. 6).

Frondicularia speciosa Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 175, pl. 11, fig. 6.

The original figure shows the sutures as double but this is due to a slightly wavy surface of the chambers. With the single broken specimen it is difficult to refer this to previously described species.

Marginulina cylindracea Karrer.

Cristellaria (Marginulina) cylindracea Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 177, pl. 11, fig. 7.

There is but a single specimen of this in the Karrer collection and it is well drawn. Without more specimens its full characters cannot be determined.

Marginulina crassicosta Karrer (Pl. 2, fig. 7).

Cristellaria (Marginulina) crassicosta Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 177, pl. 11, fig. 8.

This is represented by the holotype only. It was evidently drawn upside down and the costae shown as very thin and sharp although the description speaks of them as thick. They are broad and rounded.

Saracenaria sinus (Karrer) (Pl. 2, fig. 8).

Cristellaria sinus Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 180, pl. 11, fig. 9.

This should be referred to *S. triangularis* d'Orbigny which Karrer records as very common in this same material.

Robulus tumidus (Karrer) (Pl. 2, fig. 9).

Cristellaria tumida Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 180, pl. 11, fig. 10.

The single specimen is the only one in the collection. It is refigured and seems to belong within the range of *R. ovalis* (Reuss) which Karrer records as very abundant in this material.

Globulina lacrima Reuss (Pl. 2, fig. 10).

Polymorphina longicollis Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 181, pl. 11, fig. 11.

The original figures do not show the sutures in their correct position. The specimens seem to indicate that they belong to Reuss' species which Karrer records as not rare in this same material.

Globulina gravis (Karrer) (Pl. 2, fig. 11).

Polymorphina gravis Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 181, pl. 11, fig. 12.
Globulina gravis Cushman and Ozawa, Proc. U. S. Nat. Mus., vol. 77, Art. 6, 1930, p. 84, pl. 21, fig. 2.

The original figure was rather more accurately drawn than many of the others but the type has been redrawn. Two other specimens from the Karrer collection found with his lot labelled "*Polymorphina longicollis*" seem to belong with this species and appear to perhaps belong to *Pseudopolymorphina*.

Globulina ampla (Karrer) (Pl. 2, fig. 12).

Polymorphina ampla Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 181, pl. 11, fig. 13.

Globulina ampla Cushman and Ozawa, Proc. U. S. Nat. Mus., vol. 77, Art. 6, 1930, p. 84, pl. 21, fig. 5.

Karrer describes the test as having a rough surface. This roughness of the surface is evidently due to erosion in this particular specimen as the other two with it are smooth.

"Truncatulina horrida Karrer" (Pl. 2, fig. 13).

Truncatulina horrida Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 183, pl. 11, fig. 14.

While there are a considerable number of specimens in the Karrer collection, most of them are much eroded. The type figure is evidently much conventionalized. From the condition of the available material it is difficult to place this in its proper generic position.

Cibicides danubius (Karrer) (Pl. 2, fig. 14).

Discorbina Danubia Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 184, pl. 11, fig. 15.

There is but one specimen in the collection and this was redrawn. It was evidently an attached specimen and abnormal in form. Karrer also records *Truncatulina convexa* Reuss from this same material and Karrer's species may be referred to *Cibicides convexa* (Reuss) as a synonym.

Anomalina fontana (Karrer) (Pl. 2, fig. 15).

Rotalia fontana Karrer, Jahrb. k. k. geol. Reichsanst., vol. 20, 1870, p. 184, pl. 11, fig. 16.

The holotype is the only specimen in the Karrer collection. The specimen was very inaccurately drawn and is redrawn on our plate. It is evidently an *Anomalina* but from the single specimen difficult to compare with other described species.

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THE VALIDITY OF THE MOLLUSCAN GENUS *CAESTOCORBULA* VINCENT.[1]

H. E. VOKES.

ABSTRACT. In 1890 E. Vincent noted the presence of an accessory siphonal plate posterior to the left valve of a specimen of *Corbula henckeliusiana* Nyst from the lower Eocene of Belgium. In 1910 he reported similar plates in two specimens referred to *Corbula regulbiensis* Morris and erected for these two species the genus *Caestocorbula*, with Nyst's form as type. Subsequent authors have generally overlooked this name and his interpretation of his material has been questioned.

Recently, however, similar accessory plates were found in Cretaceous species from Texas and from the Lebanon mountains of western Asia. Further investigation resulted in the discovery of several additional examples showing this feature and, at present, siphonal plates are known from eight species. These fall into two separate groups distinguished not only by differences in the shape and ornamentation of the siphonal plates, but also by differences in the shape and proportions of the shells themselves. The name *Caestocorbula* is retained for one of these groups and a new name *Parmicorbula*, with *Corbula neaeroides* Blanckenhorn as type, is proposed for the other. Both groups, so far as now known, range from the Aptian, lower Cretaceous through middle Eocene time.

THE Cretaceous and early Tertiary faunas contain a number of species of corbulid pelecypods in which the right valve is sharply produced posteriorly into a sort of rostral "snout," while the left valve is more nearly equilateral in shape and lacks all trace of posterior prolongation. The fact that this posterior "snout" served to accommodate the siphons is demonstrated by the presence of a definite median longitudinal ridge on the inner face of the prolongation. This ridge would have separated the two during the periods when they were extended.

In 1890 Vincent described and figured (1890, p. vii) a specimen of "*Corbula henckeliusi*"[2] Nyst from the "sables de Wemmel" in which he had found a small supplementary plate within the posterior prolongation of the right valve. This plate seemed to have served as protection for the left side of the siphons in place of a complementary prolongation of the left valve. He described it as follows:

"Cette plaque, vue de face, a la forme d'un parallélogramme

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior.

[2] Error *pro Corbula henckeliusiana* Nyst (1836, p. 4, pl. 1, figs. 8a, b); see also Nyst, 1843, pp. 63, 64, pl. 2, figs. 3a, a′, b, b′).

oblique, incliné vers la gauche. Elle est légèrement courbée d'avant en arrière et divisée en deux par une arête obtuse qui la coupe en diagonale, produisant deux surfaces triangulaires; celles-ci sont inclinées de part et d'autre de l'arête, et font entre elles un angle d'une centaine de degrés. Elle est formée de lames plus ou moins imbriquées, et son accroissement s'opérait comme celui des opercules à nucléus apical de certains univalves. Enfin, cette plaque est libre, ce qui fait supposer qu'elle était seulement reliée à l'épiderme.

"Notre espèce, telle quon la connaissait, était très asymétrique; mais l'appareil dont il vient d'être question modifie en grande partie cet état. Cet appariel est évidemment l'homologue du rostre, que nous considerouns lui-même, dans notre espèce, comme une pièce appendiculaire soudée à la valve droite."

Later (1910, pp. 140-142) he reported the discovery of a similar siphonal plate in "*Corbula*" *regulbiensis* Morris and figured two specimens, which he referred to this species, in which such a plate was preserved. One of these specimens from the "Corbula band" of the Thanetian, Eocene, was found between Reculvers and Herne-bay in Kent, England. It seems to be correctly identified. The other, from the "sables de Bracheux" at Chalons-sur-Vesle, is certainly not conspecific with the former. It is difficult to say at the present time just what species is represented, although it may possibly represent a specimen of "*Corbula*" *lamarcki* Deshayes. Concerning the plates of these specimens, Vincent says:

"La plaque de *C. regulbiensis* diffère de celle de la Corbule des sables de Wemmel par sa moindre convexité et par son mode d'accroissement. Chez cette dernière espèce, la croissance de la plaque s'effectuatit à la fois en longeur et en hauteur, comme le montrent dépôts successifs de calcaire en forme de chevrons; chez la première, au contraire, elle avait lieu par la sécrétion régulière des bands verticales seulement, comme en témoignent les stries d'accorissement allant du bord dorsal au bord ventral de la plaque."

The discovery of these specimens led Vincent to propose the generic name *Caestrocorbula*, which he characterized as follows: "Coquille très inéquivalve; valve droit rostrée; valve gauche non rostrée, mais prolongée en arrière par une plaque siphonal libre. Le type du groupe est l' espèce des sables de Wemmel."

So far as the writer is aware this name was not used and remained in obscurity until 1926, when Miss Gardner (1926, p. 44) made the following statement.

"*Caestocorbula* Vincent, type *Corbula henckeliusi* Nyst, is . . . a synonym of *Corbula* s.s. *Caestocorbula* was founded upon the supposed presence of a siphonal plate. The nature of the plate and the mode of attachment are not obvious from the description or the figure, but the plate is either quite foreign

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EXPLANATION OF PLATE 1.

Figs. 1-6, *Caestocorbula* Vincent, 1910.

1. Vincent's original illustration of the siphonal plate in "*Corbula henckeliusi*" Nyst.
2. *Caestocorbula elegans* Sowerby. Reproducton of Woods' figure, pl. 34, fig. 28a. Magnification said to be X5.
3. *Caestocorbula crassiplica* (Gabb). Ripley formation, Coon Creek, Tennessee. X4; U. S. Nat. Mus. Cat. No. 103712.

4-6. *Caestocorbula ficus* (Brander). Eocene, Wemmel, Belgium. This species was said by Vincent to be synonymous with *C. henckeliusiana*. 4. Interior of right valve, X2; U. S. Nat. Mus. Cat. No. 13070. 5. Both valves, viewed from left side, X2. U. S. Nat. Mus. Cat. No. 13070. 6. Exterior of right valve, X2; same specimen as fig. 4.

Figs. 7-18, *Parmicorbula* new genus.

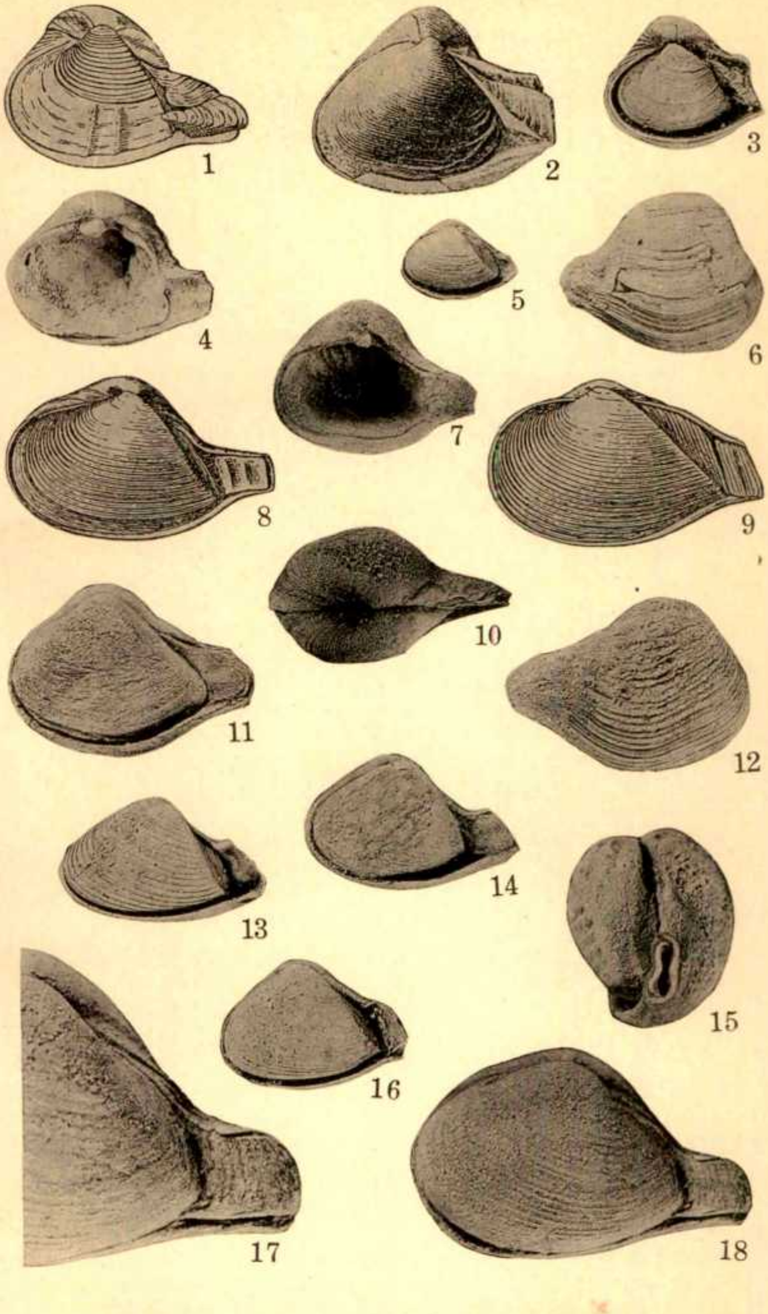
7, 10-12, 14, 15. *Parmicorbula neaeroides* (Blanckenhorn). Aptian, Cretaceous, Abeih, Lebanon Mountain, Lebanon. Type of *Parmicorbula*. 7. Interior of right valve, X1.5; Am. Mus. Nat. Hist. Cat. No. 16403/4:2. 10. Dorsal view of paired valves, X1.5; Am. Mus. Nat. Hist. Cat. No. 16403/4:1. 11. Both valves viewed from left side, X1.5, same specimen as fig. 10. 12. Right valve, X1.5; same specimen as figs. 10, 11. 14. Young specimen with siphonal plate in position, X4; Am. Mus. Nat. Hist. Cat. No. 16403/4:3. 15. Posterior view to show siphonal plate in position, X6; same specimen as fig. 14.

8. *Parmicorbula regulbiensis* (Morris) Thanetian, Eocene, Herne Bay, Kent, England. Reproduction of Vincent's figure, said to be X3.

9. *Parmicorbula* sp. Thanetian (?), Eocene, Chalons-sur-Vesle, France. (= ? "*Corbula*" *lamarcki* Deshayes). Figured by Vincent as *Corbula regulbiensis* Morris, said to be X3.5.

13, 16. *Parmicorbula suffalciata* (Wade), Ripley formation, Cretaceous, Coon Creek, Tennessee. 13. Both valves, viewed from left, X4. Note the manner in which the dorsal and ventral margins of the right valve are bent to receive the siphonal plate, which is missing here. U. S. Nat. Mus. Cat. No. 103711. 16. Both valves, viewed from left, with siphonal plate in position, X4; U. S. Nat. Mus. Cat. No. 103710.

17, 18. *Parmicorbula* n. sp. (Stephenson ms.), Lewisville member, Woodbine formation, Cretaceous, Texas. 17. Siphonal plate in position, X6; U. S. Nat. Mus. Cat. No. 103713. 18. Both valves, viewed from left, with siphonal plate in position, X4; same specimen as fig. 17.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to the shell or a fortuitous character resulting possibly from some of the peculiar phenomena of breakage that the Corbulae occasionally show."

The same statement was repeated in 1928 (p. 227), and her conclusions regarding the nature of the siphonal plate were accepted, in manuscript, by the writer during the preparation of a report on the "Superspecific groups of the Family Corbulidae." In that report, however, it was noted that, although the name *Caestocorbula* seemed to be based upon a misconception as to the characteristics of the designated type species it is wholly available for the group of species included within the limits of the characters embraced by Nyst's species.

Just at this time, however, Dr. L. W. Stephenson was engaged in the preparation of a monograph on the fauna of the Lewisville member of the Woodbine formation of the Texas Cretaceous. While examining the corbulid species of this collection Doctor Stephenson and the writer both became aware of the fact that a peculiar structure, which Doctor Stephenson had noted on the posterior portion of one of his specimens, actually represented a siphonal plate similar to those described by Vincent. (See Pl. 1, Figs. 17, 18.)

The discovery of this specimen led to an examination of a series of specimens of "*Corbula*" *neaeroides* Blanckenhorn (1890, p. 96, Pl. 7, Figs. 3a, b, c) from the Aptian of the Lebanon Mountains, Republic of Lebanon, which had already been referred in manuscript to *Caestocorbula*. Seven immature specimens in this collection proved to have the siphonal plates preserved. (Pl. 1, Figs. 14, 15.)

Further examination of specimens in the collections at the United States National Museum led to the discovery of a specimen of "*Corbulamella*" *suffalciata* Wade[3] (1926, p. 97 Pl. 31, Figs. 15, 16, 19, 20) in which a well-preserved plate was present (Pl. 1, Fig. 16) and of more than a dozen specimens of "*Corbula*" *crassiplica* Gabb (1860, p. 394, Pl. 58, Fig. 25) also containing siphonal plates (Pl. 1, Fig. 3). All of these specimens are from the Ripley formation at Coon Creek, Tennessee.

[3] This species differs in nearly all respects from *Corbulamella gregaria* Meek and Hayden, the type of *Corbulamella*. A number of corbuloid species possess a raised platform for the reception of the posterior muscle scar, and that which is found in Wade's species is quite different from the spoon-shaped process which projects from the posterior dorsal portion of the shell in *Corbulamella*. Strictly interpreted *Corbulamella* appears to be still a monotypic genus.

In addition to these four Cretaceous species in which plates have been found, a similar structure is clearly to be observed in the specimen of "*Corbula*" *elegans* Sowerby figured by Woods (1908, Pl. 34, Figs. 28a, b).

Thus, the presence of siphonal plates has been demonstrated for the following eight species:

Eocene:
C. henckeluisiana Nyst ....Wemmelian-Thanetian, Belgium.
C. regulbiensis Morris ....Thanetian, England.
"*C.*" sp. (figured by Vincent as *C. regulbiensis* =
? "*C.*" *lamarcki* Desh.) ....Thanetian, France.
Cretaceous:
"*C.*" *neaeroides* Blanckenhorn ....Aptian, Lebanon.
"*C.*" *elegans* Sowerby ....Cenomanian, England.
New species, (Stephenson, Ms.)
Woodbine formation (Cenomanian), United States.
"*C.*" *crassiplica* Gabb ....Ripley formation (Maestrichtian) United States.
"*Corbulamella*" *suffalciata* Wade
Ripley formation (Maestrichtian) United States.

As noted by Vincent (see above), there are two types of siphonal plates. In *C. henckeluisiana*, *C. elegans*, and *C. crassiplica* the plates form an oblique trapezium which is inclined toward the left and extends from the rostral portion of the right valve dorsad along the posterior dorsal edge of the left. There is a median ridge extending diagonally across it from the acute dorsal angle to the broader posterior ventral angle. The growth lines form a chevron-shaped pattern and occasionally form raised lamellar ridges. The dorsal margin of the right valve tends to overlap slightly the margin of the plate, aiding in holding it in position. There is no similar structure along the ventral margin of the right valve which tends to flare rather widely below the margin of the left valve. This is the true *Caestocorbula*.

In "*Corbula*" *neaeroides*, "*C.*" *regulbiensis*, "*C.*" sp. (Vincent), "*Corbulamella*" *suffalciata*, and Doctor Stephenson's new species the plate is of a more simple type being essentially rectangular with the dorsal edges sharply angulate and produced laterally to form narrow flanges which are received inside the dorsal and ventral margins of the rostrum of the right valve. These margins also are twisted laterally to form flanges similar to those of the plate itself. Growth took place at the end of the plate, and the growth lines trend transversely across it.

The manner in which these plates fit together clearly shows that they are not foreign to the shells, nor are to be accounted for by any phenomena of breakage. Furthermore, there is a broad, shallow, and inconspicuous longitudinal median groove on the exterior of the plate which, when viewed from the end of the shell (Pl. 1, Fig. 15) is seen to be complementary to a low ridge on the inner side of the plate. This ridge is immediately opposite the median ridge on the rostrum of the right valve. Together they divide the area within the rostrum into two separated tubes for the passage of the siphons and give the outline of the inner margins of the posterior area a distinctive "figure 8" shape.

There are thus two distinctively different types of species bearing siphonal plates of a different character and mode of growth. An examination of the collections shows that they occur in association, both first appearing, so far as present knowledge is concerned, in the Aptian of the Lebanon Mountains[4] and extending up into the upper Eocene. Both groups are represented in the Thanetian by specimens in which the plates are preserved (*Caestocorbula henckeluisiana* and "*Corbula*" *regulbiensis*) and in the middle Eocene by species which, on their shape, seem clearly referable to them. "*Corbula*" *wailesiana* Harris from the Jackson formation of Mississippi, Arkansas, and Texas (probably of Bartonian age) is a *Caestocorbula*, and "*Corbula*" *gibbosa* Lea from the Claiborne sand of Alabama belongs to the *neaeroides* group.

The new generic name *Parmicorbula* is therefore proposed for the latter group of species with "*Corbula*" *neaeroides* Blanckenhorn as the type species. The name is a combination of the Latin "*parma*" (a small shield) and *Corbula* and is in allusion to the protection furnished the siphons by the siphonal plate.

The two genera may be diagnosed as follows:

CAESTOCORBULA Vincent, 1910

Plate 1, Figures 1-6.

Caestocorbula Vincent, 1910, Soc. Roy. Zool. Malac, de Belg., Ann. (for 1909), p. 191.

[4] "*Corbula*" *olivae* Whitfield (1891), p. 418, pl. 7, figs. 19-21) clearly belongs to *Caestocorbula*. This determination is based upon the shape of the valves, for the small collection available contains no specimens in which the plate is preserved.

Type, by original designation, *Corbula henokeluisi* Nyst [error *pro C. henokeluisiana* Nyst].

The shell is relatively small and very inequivalved. The right valve is larger than the left, more inflated and produced posteriorly to form a prominent rostral "snout"; its surface is sculptured by coarse concentric ribs. The left valve is almost equilateral, sub-triangular in outline, not produced posteriorly, but bearing a prominent posterior umbonal ridge. The dorsal margins of the right valve are strongly grooved for the reception of the margins of the left; the posterior dorsal margin of the right valve is sharply bent laterally to meet the dorsal margin of a small, separate siphonal plate which served to protect the siphons in place of a rostrum from the left valve.

The siphonal plate has the form of an oblique trapezium with the more acute angle at the anterior dorsal corner, which lies against the posterior dorsal side of the left valve. The surface bears a distinct oblique median ridge that extends diagonally across the plate from the acute dorsal angle to the broader posterior ventral one. The surface of the plate is ornamented by raised lamellar growth lines that are chevron-shaped and parallel to the posterior and ventral margins of the plate.

The right cardinal tooth is triangular, relatively large, and heavy, and the resilial pit is prominent and elongate, extending dorsad slightly above the posterior side of the cardinal tooth. The left hinge consists of an anterior cardinal socket followed posteriorly by a moderately broad, projecting chondrophore.

The muscle scars are slightly thickened and rugose; the pallial sinus is extremely well developed for the family Corbulidae, broad, and rounded.

Remarks.—There are three species: *Caestocorbula henckeluisiana*, *C. elegans* (Sowerby), and *C. crassiplica* (Gabb) in which plates of the form characteristic of this genus have been found. In addition to these the following species have been noted during a cursory examination of collections and of published illustrations, which, on the basis of the shape of the shell itself, seem most probably to be referable to this genus:

"*Corbula*" *olivae* Whitfield: Aptian; Lebanon Mountains, Republic of Lebanon.

"*Corbula*" *angustata* Sowerby: Cenomanian; Europe.

"*Corbula*" *parsura* Stoliczka; Trichnipoly group, India.

"Corbula" rugosa Lamarck; Cuisian to Bartonian; western Europe.
"Corbula" costata Sowerby; Lutetian and Bartonian; western Europe.
"Corbula" ficus Brander; Lutetian and Bartonian; western Europe.
"Corbula" fossata Aldrich; Lisbon formation, Eocene; Mississippi.
"Corbula" wailesiana Harris; Jackson formation, Eocene; Mississippi, Arkansas, and Texas.
"Corbula" smithvillensis Harris; Mount Selman formation, Eocene; Texas.
"Corbula" texana Gabb; Mount Selman formation, Eocene; Texas.

PARMICORBULA, new genus.

Plate 1, Figures 7-18.

Type species: *Corbula neaeroides* Blanckenhorn [Aptian, Cretaceous, at Abeih, Lebanon Mountains, Republic of Lebanon]; (Pl. 1, Figs. 7, 10-12, 14, 15).

The shell is of moderate size, moderately inflated, and very inequivalved. The right valve is larger than the left, more inflated and produced posteriorly to form a prominent rostral "snout"; its surface is ornamented by coarse concentric ribs that die out before reaching the rostrum, so that the latter is generally relatively smooth. The left valve is almost equilateral, not produced posteriorly, but bearing a moderately prominent posterior umbonal ridge; the surface is marked by concentric ribbing, which is generally finer than that on the right valve. Occasionally, there are traces of radial ribbing present. The dorsal margins of the right valve are grooved for the reception of those of the left, and just within the ventral margin there is a linear depression against the inner side of which the left valve rested.

Both the posterior dorsal and posterior ventral margins of the right valve are constricted at the anterior end of the rostrum, and along that structure are sharply bent laterally to receive between them the similarly bent margins of a small, rectangular siphonal plate. The exterior of this plate is marked by a shallow, inconspicuous, median groove, and by growth lines which run transversely across it. Internally there is a low, median ridge, complementary to a similar ridge trending parallel to the length of the rostrum of the right valve.

The hinge, muscle impressions, and pallial sinus are similar to those of *Caestocorbula*.

Remarks.—Siphonal plates of the type characteristic of this

genus have been observed in four species: "*Corbula*" *neaeroides* Blanckenhorn, "*Corbula*" *regulbiensis* Morris, "*Corbula*" sp. (Vincent) [?= *Corbula lamarcki* Deshayes], and *Parmicorbula* n. sp. (Stephenson, ms.). Judging from the shape of the shells, the following species are also expected to prove referable to *Parmicorbula*:

"*Corbula*" *substriatula* D'Orbigny; Senonian of Europe.
"*Corbula*" *striatuloides* Forbes; Trichnipoly group, India.
"*Corbula*" *terramaria* Gardner; Monmouth formation, Cretaceous; Maryland.
"*Corbula*" *longirostris* Deshayes; Lutetian, Eocene; western Europe.
"*Corbula*" *gibbosa* Lea; Claiborne, Eocene; Alabama.
"*Corbula*" *aldrichi* Meyer; Woods Bluff (Wilcox), Eocene; Alabama.

The species included in the lists given above for *Caestocorbula* and for *Parmicorbula* are only those observed in a rapid reconnaissance of the paleontologic literature. The lists are in no sense complete, but they do serve to indicate that species of these genera were widely distributed during the Cretaceous and Eocene times and accentuate the fact that siphonal plates are to be looked for in every collection representing species from these periods.

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THE MOBILITY OF GREENLAND.

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DR. F. Loewe, writing from the University of Melbourne, has kindly called my attention to an important article by N. E. Nörland, Director of the British Geodetic Institute, in which the results of longitude determinations in Greenland are summarized (1937). In the George Darwin Lecture delivered before the Royal Astronomical Society in May, 1937, Doctor Nörland discussed "Astronomical Longitude and Azimuth Determinations," and referred to triangulations carried out under his leadership in Denmark and Greenland. His concluding paragraph is quoted here.

"I just mentioned that we recently carried out a number of longitude determinations in Greenland, and I shall conclude with a short remark on these observations. We know that Wegener considered that his hypothesis of displacement of continents had been supported by longitude determinations in Greenland, and from them he calculated that Greenland is moving westward about 20 metres a year. But the old observations used by Wegener were carried out with primitive instruments and he overrated their exactitude. In 1927 and 1936 the Danish Geodetic Institute carried out longitude determinations at Kornok on the west coast of Greenland with a first-class transit instrument, both times on the same pillar. Practically speaking the two measurements gave the same result. It is most likely that the deviations of the old observations from the new ones are the result of observation errors."

As du Toit states (1937), Jensen made a determination of longitude at Kornok in 1922, and the station was reoccupied by Gabel-Jörgensen in 1927. Comparison of the results was accepted by Wegener and du Toit as a demonstration that Kornok—and presumably Greenland—moved westward during the five-year interval at a yearly rate of about 36 metres. However the determinations of 1927 and 1936, accepted as reliable by the Danish Institute, indicate no movement during that nine-year period. At present, therefore, there seems to be no basis for any claim that longitude determinations in western Greenland support the concept of continental drift.

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DISCUSSION.

AUGITE IN HAWAIIAN BASALT

Recently an interesting paper by Gordon A. Macdonald appeared in this Journal.[1] The writer wishes to comment on a minor point in that paper.

On page 184 Macdonald describes a pale brown microphenocryst of *pigeonite* with $+2V=45°\pm$.

The writer discussed pyroxenes of basaltic magmas at some length a few years ago.[2] Edwards at the same time independently arrived at practically identical conclusions as to the phase relations of certain pyroxenes in such magmas.[3] The conclusions are also accepted with a few reservations by Walker[4] who has investigated pyroxenes of dolerites and diabases of Scotland, the Palisades and the Karroo.

While the writer does not wish to force his suggested nomenclature for pyroxenes on unwilling petrologists, he would like to make a strong plea that at least that portion be accepted which limits the use of the term pigeonite to one of the two phases of clinopyroxene which may separate from basaltic magmas. If some such distinction is not made, there will be continued confusion in the understanding of phase relationships within basaltic magmas.

The commonest clinopyroxene of diabases and basalts normally has an optic angle of approximately 45° and the writer has suggested that this be called *augite.* Clinopyroxene phenocrysts in flows may have somewhat larger optic angles (50°-60°). Pigeonites as defined by the writer normally have optic angles ranging from 0° to 25° and very rarely reach 30°. There is a gap in observed optic angle ranges between augite and pigeonite. The microphenocryst described by Macdonald is from the writer's point of view, common augite.

H. H. HESS, LT. COMDR. U.S.N.R.

[1] Macdonald, Gordon A.: 1944. The 1840 eruption and differentiation in the Kilauean Magma Column. Amer. Jour. Sci. 242, pp. 177-189.
[2] Hess, H. H.: 1941. Amer. Mineral., 26, 515-535, 573-594.
[3] Edwards, A. B.: 1942. Jour. Geol. 50, pp. 451-480, 579-610.
[4] Walker, F.: 1943. Amer. Mineral., 241, pp. 517-520.

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DISCUSSION.

PYROXENES IN HAWAIIAN LAVAS.[1]

The foregoing criticism by Hess of a paper by the writer on the 1840 lava flows of Kilauea[2] raises several points regarding the pyroxenes of basaltic lavas and Hess' classification of pyroxenes in general which require brief discussion. The general features will be treated first.

In Hess' classification[3] the name *salite* is applied to a group of monoclinic pyroxenes lying close to the diopside-hedenbergite join which for many years have been practically unanimously termed *augite,* whereas the name *augite,* is restricted by him to pyroxenes containing 25 to 45 per cent $CaSiO_3$. The latter group of pyroxenes apparently has optic angles that range as low as 40°, as shown on the curves given by Wager and Deer,[4] and therefore includes members that many petrographers have considered to fall within the range of *pigeonite.*

Hess believes that there exists a compositional gap between monoclinic pyroxenes with optic angles of about 30° or less and those with optic angles of about 40° and more, and accordingly he suggests that the name *pigeonite* be restricted to those having optic angles of less than 32°. In regard to the pyroxenes of intrusive rocks the evidence does indeed appear to indicate such a gap, but for the pyroxenes of rapidly cooled extrusive rocks the evidence is much less convincing. It is based on the fact that most published optic angle determinations fall below 30° or above 40°. The groundmass pyroxenes of volcanic rocks are generally of very small size and difficult to work with, however, and reliable determinations of their optic angles are few. Most writers have been content to state that optic angles of groundmass pyroxenes of mafic lavas range from 0° to about 50°. Such statements, of course, are of little value in a statistical study of the size distribution of optic angles, but do imply

[1] Published by permission of the Director, Geological Survey, U. S. Department of the Interior.

[2] Macdonald, G. A.: 1944, The 1840 eruption and crystal differentiation in the Kilauean magma column, Amer. Jour. Sci., vol. 242, pp. 177-189.

[3] Hess, H. H.: 1941, Pyroxenes of common mafic magmas, Amer. Mineralogist, vol. 26, pp. 515-535, 573-594.

[4] Wager, L. R., and Deer, W. A.: 1939, Geological investigations in East Greenland, Part 3, The Petrology of the Skaergaard Intrusion, Kangerdlugssuaq, East Greenland, Med. om Grønland, Komm. for Videnskabelige undersøgelser i Grønland, Bd. 105, Nr. 4, pp. 80.

a belief on the part of the investigators that a more or less continuous size gradation exists.

The only thorough study of the groundmass pyroxenes of a single lava known to the writer is that by Kuno,[5] in which he measured the optic angles of 46 grains of monoclinic pyroxene in an andesite of Hakone Volcano. He found that the values tend to fall in two groups, one near 0° and the other near 40°, with none between 29° and 36°. Furthermore, the elimination of one value of 29° and one of 36° leaves a gap between 17° and 39°. This gap was used by Hess as supporting evidence that the limited miscibility found among the pyroxenes of the intrusive rocks exists also in the extrusives. The measurements of 29° and 36° nevertheless do exist, and they reduce the actual gap at this point to a maximum of 7°. A larger gap of 12° exists between the measured values of 17° and 29°, but falls within the range in which many pigeonites are known to exist in other rocks. It is to be expected that other measurements will be found still further reducing the 7° gap, and probably entirely bridging it. Compositionally, pyroxenes of the Downes Mountain sill appear to fall at about this point[6] and Walker's statements[7] also appear to indicate a lack of any gap in 2V above 32°. Although there are almost certainly more pyroxenes having optic angles of less than 30° and greater than 39°, it may be questioned whether any actual gap in composition exists. It appears more probable that among the metastable monoclinic pyroxenes of extrusive rocks there is a continuous gradation from those with an optic angle of 0° to those with optic angles of 50° or more. The same conclusion was reached by Edwards in his excellent discussion of monoclinic pyroxenes. He says: "It seems probable, however, that the width of the immiscibility gap between the augite series and the clinoenstatite series ranges from zero to a maximum according to the temperature and particularly the rate at which crystallization takes place. At high temperatures and with rapid cooling, complete miscibility is found; at lower temperatures and with slow cooling a maximum immiscibility results."[8]

In the preceding discussion by Hess, he states that the commonest monoclinic pyroxene of basalts normally has an optic angle of approximately 45°. In the basalts of the Hawaiian and Samoan Islands that is definitely not so. In these lavas, with the exception of the picrite-basalts, groundmass pyroxene greatly exceeds in

[5] Kuno, H., 1936, Petrological notes on pyroxene andesites, Hakone Volcano, Jap. Jour. Geol. and Geogr., vol. 13, pp. 107-140.

[6] Edwards, A. B.: 1942, Differentiation of the dolerites of Tasmania, Jour. Geology, vol. 50, pp. 451-480, 579-610. See especially pp. 600, 602.

[7] Walker, F.: 1943, Note on the pyroxenes of basaltic magma, Amer. Jour. Sci., vol. 241, pp. 517-520.

[8] Edwards, A. B.: Op. cit., p. 602.

amount the pyroxene phenocrysts. In most specimens the groundmass pyroxene shows optic angles ranging from near 0° to about 50°, small angles predominating over the larger ones. The variation occurs among grains in single specimens, and to some extent even within single grains. There appears to be a complete gradation in size of the optic angle from one end of the series to the other, but this cannot be definitely asserted, as determinations are based on estimation from the appearance of interference figures rather than on instrumental measurements. The writer has seen no evidence whatever for the separation of the groundmass pyroxene into two sharply distinguished types. Determination of the orientation of the optic plane has not been attempted, however, as cleavage is generally so poorly developed that no reliable direction of reference is available.

In the lavas of Hawaii and Samoa phenocrysts of monoclinic pyroxene, when they occur, have optic angles ranging from 50° to 60°. They would be termed *salite* by Hess, but the writer prefers to retain for them the familiar term *augite*. Microphenocrysts, such as those in the 1840 lava, are related genetically and compositionally to the groundmass pyroxenes, rather than to the true phenocrysts. They grade in size imperceptibly into the groundmass, and many show outer zones in which the optic angle has the small size characteristic of the groundmass pyroxene. In the core of the microphenocryst the estimated optic angle is generally 40° to 45°, values falling within the range of augite in Hess' classification, but distinctly less than those in the associated true phenocrysts. Further evidence of the relationship of the microphenocrysts to the groundmass pyroxene is found in rocks that contain both microphenocrysts and megaphenocrysts of monoclinic pyroxene. In such rocks the megaphenocrysts are generally partly resorbed, whereas the microphenocrysts show no signs of resorption. There are, of course, some true phenocrysts of microscopic size, but they show the same large optic angle, evidences of resorption as do the larger grains. The megaphenocrysts definitely belong to an intratelluric generation older than the microphenocrysts. This is in agreement with the older observations of Barth[9] and Tsuboi[10] that megaphenocrysts of pigeonite (in the old sense) occur only very rarely.

There remains to be considered Hess' original criticism. A microphenocryst in the 1840 lava of Kilauea, with a 2V of 45°, was named pigeonite by the writer, but would be called augite by Hess. Like Walker,[11] the writer is willing to accept a 2V of 32° as an

[9] Barth, T. F. W.: 1931, Crystallization of pyroxenes from basalts, Amer. Mineralogist, vol. 16, pp. 195-208.

[10] Tsuboi, S.: 1932, On the course of crystallization of pyroxenes from rock magmas, Jap. Jour. Geol. and Geogr., vol. 10, pp. 67-82.

[11] Walker, F.: Op. cit., p. 518.

upper limiting value for pigeonite, regardless of the orientation of the optic axial plane. That would place such grains as the microphenocryst in question in the field of augite. However, he feels that their more pigeonitic composition, as compared with the augite phenocrysts, and in mid-Pacific lavas their genetic relationship with the true pigeonite of the groundmass, should be emphasized. Consequently he suggests the name *pigeonitic augite* for such pyroxenes in the mid-Pacific lavas, and possibly for such pyroxenes in general. The use of the name pigeonitic augite for this group of minerals would eliminate the necessity of using the unfamiliar name salite for the pyroxenes closer to the diopside-hedenbergite join, which could continue to be known by their familiar designation augite, and would indicate more clearly the identity of part of the present augite group with material formerly termed pigeonite.

In conclusion, the writer wishes to point out that the above remarks bear on only a small part of Hess' discussion of monoclinic pyroxenes, and that Hess' work remains, in the writer's opinion, a valuable contribution to the understanding of an important group of igneous minerals.

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SCIENTIFIC INTELLIGENCE

Physics and Chemistry.

An Introduction to Physical Statistics; by Robert Bruce Lindsay. Pp. ix, 306; 11 figs. New York and London, 1941 (John Wiley & Sons, Inc., $3.75).—If one accepts a widening use of a scientific discipline as a measure of its importance, the necessary appearance of more and more elementary expositions of the subject is a corollary of the theorem implied. The term "elementary" is used in its non-technical sense: the fundamentals of statistical mechanics are elementary or not according to the mental capacity of the student. In any case they can be presented in a moderately non-technical fashion, not beclouded by a dense haze of mathematical symbols. The proof of this statement may be readily obtained by Lindsay's book. Professor Lindsay sets out to provide "a thorough but not too lengthy introduction to the method of statistical physics . . . for readers equipped with an introductory background in theoretical physics." He succeeds admirably. The author has not attempted to present a thoroughly logical exposition of statistical mechanics from a single point of view. Such expositions may be found in other places. Rather, he has done something much more important for the student; he has given an account of various phases of the subject in such a way that the relations between them are shown with great clarity. After introductory chapters on the character of statistical theories, elementary probability and the theory of errors, and on thermodynamics, the author takes up in succession Maxwell-Boltzman statistics, an interlude on the kinetic theory of gases, classical statistics by the Gibbs method, and statistical mechanics by the method of Darwin and Fowler. The Darwin-Fowler method is then applied to the development of the fundamentals of quantum statistics. The three concluding chapters contain applications of the methods to gases and solids, to the theory of metals, and to the emission of electrons from surfaces. All this in the space of three hundred pages; with problems. If one must find fault: the brevity of some of the discussions may possibly be misleading. For example, from pages 31-33 one might get the idea that Poissan's distribution law is the last word to be said on the subject of radioactive disintegrations. (Actually it is strictly applicable only in the case of very long-lived substances.) It is, however, scarcely fair to criticize an almost necessary characteristic of "a not too lengthy introduction" to a subject.

It may be worth mentioning that a smattering of vector analysis will be useful to the reader and that he should have at least a speaking acquaintance with integration in the complex plane.

The typography of the book is excellent; the equations and formulae are clearly set forth. Insofar as the reviewer is aware this book is the only one on its subject to be had at so low a price.

HENRY C. THOMAS.

Mr. Tompkins Explores the Atom; by G. GAMOW, Pp. x, 97; 22 figs. New York, 1944 (The Macmillan Co., $2.00).—In his latest book in popular science, Gamow continues to use the characters introduced in *Mr. Tompkins in Wonderland.* They are: Mr. Tompkins, a bank clerk; his wife, Maud, the daughter of a Physics professor; and the old professor.

The reader is first told the story of the dreams of Mr. Tompkins and Maud and in this way is introduced to the facts of the kinetic theory of matter, properties of the electrons and their place in an atom, and some ideas of the nucleus and nuclear structure. This is relatively light reading but provides a vivid pictorial background for the facts which are presented more logically in the four lectures which appear in the appendix.

In his appendix Gamow describes the experiments and facts which gave rise to the kinetic theory of matter and introduces the concept of the atom. Next he discusses the structure of the atom and some of the properties of the electron. He devotes an entire lecture to Dirac's theory of the electron and the positron and makes it sound plausible. He concludes his lectures by a discussion of nuclear particles, nuclear forces, and nuclear structure.

The dreams are entertaining enough to make excellent reading for anyone. They dispel any prejudice the reader may have had toward Physics and inspire him to read the appendix. The appendix although easily enough understood by the layman would make good supplementary reading for a college course in Physics.

ROLAND E. MEYEROTT.

Colorimetric Determination of Traces of Metals (Chemical Analysis, Vol. III); by E. B. SANDELL. Pp. XVI, 487; 78 figs. New York, 1944 (Interscience Publishers, Inc., $7.00).—The determination of constituents present in quantities of less than 0.01%, while once considered to be either impracticable or not worth the trouble, has in recent years become an important field in analytical chemistry. This excellent book reflects the rapid progress of the last fifteen years in the development of colorimetric methods. Many sensitive reactions have been discovered, and procedures have been developed for determination of as low as 10^{-5}% of certain elements. Nevertheless, the author is careful to emphasize that our knowledge of the application of these reactions is still so imperfect that much work must yet be done on separation of traces and the effect of foreign elements on each color reaction. In the first part

of the book the author presents the broader aspects of trace analysis. There are chapters dealing with methods of separation and isolation of traces; the optical methods of colorimetry, spectrophotometry, and fluorimetry; and colorimetric reagents which are of general application such as dithizone. In the latter part of the book the author has collected procedures for the determination of traces of forty-five metals and the rare-earths. Only a limited number of methods best suited to trace determinations have been chosen, and to a considerable extent these methods are based on the experience of the author. There are frequent references to the original articles, many as recent as 1948. Explicit directions are given for each determination. The standard curves which are often included should be very helpful. The usefulness of the book is further increased by the inclusion of many modifications of the procedures for application to special substances such as biological materials, silicate rocks, ores, steel, and other alloys.

E. J. KING.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

A Shorter History of Science; by SIR WILLIAM CECIL DAMPIER. Pp. x, 189. New York, 1944 (Macmillan Company, $2.00).—Sir William Cecil Dampier (formerly Whetham) is the author of several well-known treatises on the history of the sciences, among them "A history of Science" and "The Recent Development of Physical Science." In his preface to the present book he indicates that the philosophic part of his larger work, which placed particular emphasis on the relations between science and philosophy, has been found difficult by numerous readers whose interest was chiefly confined to science. Hence he offers here a straightforward account "of the growth of science reduced to its simplest terms."

The rendering of the account is excellent beyond question. Despite the stated restriction, large perspective is present everywhere; the book is no mere enumeration of scientific discoveries but the sympathetic tale of the unfolding of the most glorious of human enterprises.

What is noteworthy is the fortunate chance that the book should appear at this time. There are far flung signs of growing disgust at the socially sterile methods of teaching science. One of the remedies which have occasionally been advocated is infusion of an historical outlook into elementary science courses. Here is a book that will adequately serve this purpose. While it is written "to meet the needs of schools" (to quote its author) it deserves a place on the desks of teachers of biology, chemistry, medicine, anthropology, psychology, mathematics, astronomy, and physics.

HENRY MARGENAU.

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COMMENTS ON THE RELATIONSHIPS OF THE CERVOID FAMILY PALAEOMERYCIDAE.

R. A. STIRTON.

ABSTRACT. The Palaeomerycidae are here defined to include the Old World and New World non-antlered but horned and some hornless cervoids. The genera with forked horns from the Old World are included in the subfamily Palaeomerycinae and those from North America with pointed, bulbous or flat tipped horns are assigned to the Dromomerycinae. The hornless genera cannot be assigned to either of these subfamilies until their relationships are better known. A phylogenetic chart and a table of comparative characters is drawn to illustrate the supposed relationships of the genera, which are discussed in the text.

No phyletic intergradation has been demonstrated between any of the genera, though *Blastomeryx* may have given rise to *Longirostromeryx*. On the other hand *Barbouromeryx-Dromomeryx* and *Bouromeryx-Cranioceras* may represent two instead of four genera.

Dremotherium from the early Lower Miocene of Europe seems nearer to the ancestry of the Palaeomerycidae and of the Cervidae than any known genus. Antlered forms (Cervidae) first appear in the late Lower Miocene of Europe (*Stephanocemus*) thus being contemporary with the earliest occurrence of most North American genera (Palaeomerycidae).

An attempt has been made to list the occurrences of the North American genera under the geological ages as ascribed by the committee on nomenclature and correlation of the North American continental Tertiary.

The suborder Pecora is divided into three superfamilies—TRAGULOIDEA (Amphimerycidae, Hypertragulidae, Protoceratidae, Tragulidae and Gelocidae); CERVOIDEA (Giraffidae, Palaeomerycidae and Cervidae); BOVOIDEA (Antilocapridae and Bovidae). The superfamily position of the Moschidae is still questionable but it seems to be closely related to certain members of the Palaeomerycidae.

IN an attempt to recognize the relationships of some Tertiary cervoid genera a brief review of the Cervoidea has been made and a preliminary phylogenetic chart drawn. The accompanying table of comparative characters will disclose in brief some of the more important characters of the genera included in the Palaeomerycidae.

It is suggested that the suborder Pecora may be divided conveniently into three superfamilies—TRAGULOIDEA (Amphimerycidae, Hypertragulidae, Protoceratidae, Tragu-

lidae and Gelocidae); CERVOIDEA (Giraffidae, Palaeomerycidae and Cervidae); BOVOIDEA (Antilocapridae and Bovidae). This classification is based on the conclusion that both the Cervidae and the Palaeomerycidae arose from a late Oligocene *Dremotherium* or a *Dremotherium*-like form, that the giraffes are descendants from the basal *Palaeomeryx* (?=*Lagomeryx*) stem possibly in early Miocene, and because the Palaeomerycidae as a whole occupy both an ancestral and an intermediate position to the Giraffidae and the Cervidae.

Most classifications have used the suborder Pecora to include those selenodont artiodactyls with incisiform lower canines, with united navicular-cuboids and with all upper incisors missing or tending in that direction. This obviously is a closely related group though *Archaeomeryx* possesses three peg-like incisors and sometimes there is a vestige of an upper incisor in *Hypertragulus*; also the navicular and cuboid are imperfectly ossified at least in some individuals of *Protoceras*. Nevertheless the group is a rather compact one and lends itself to subordinal classification. Unfortunately for an arrangement of groups into equivalent rank, the Traguloidea on the one hand and the Cervoidea + the Bovoidea on the other seem to be of about the same rank.

TRAGULOIDEA.	CERVOIDEA + BOVOIDEA.
Lower premolars somewhat trenchant, with inflections opening posteriorly; metapodials not fused into cannon-bones, with keels of distal facets on posterior surface.	Lower premolars with inflections opening lingually; metapodials II-III fused into cannon-bones, with keels of distal facets continuous from posterior to anterior surface.

This offers an excellent example of the difficulty encountered in taxonomical classification. Because of the kinds of animals represented, another category is needed here to occupy a rank somewhere between the suborder and superfamily, though it is not at all practical to propose such a category. Colbert (1941, p. 21) has attempted to solve this difficulty by recognizing the Tragulina as of subordinal rank and limiting the Pecora to include the deer, giraffes and bovids. This presents a clearer expression of the traguloids and related families but obscures the broader relationships of the Pecora as a whole. It has frequently been stated that a classification of the Artiodactyla is a difficult problem.

The Cervoidea and Bovoidea, however, may be diagnosed as follows:

CERVOIDEA.	BOVOIDEA.
Hornless or with solid horns; cheekteeth brachyodont or hypso-brachyodont, enamel surface crenulated.	Hornless or with hollow horns; cheekteeth brachy-hypsodont or hypsodont, enamel surface only slightly if at all crenulated.

ORIGIN OF THE CERVOIDEA.

Matthew (1908) has pointed out strong evidence for the origin of the Cervoidea from *Leptomeryx* of the North American Oligocene. He also suggested that some of the genera may have descended from the European *Prodremotherium*; but the presence of palaeomeryx-folds in *Leptomeryx* together with numerous other primitive cervoid characters would seem to place it nearer the ancestry of the group as a whole.

In 1925, however, Matthew and Granger considered *Eumeryx culminis* from the Hsanda Gol fauna of Mongolia as a primitive member of the family Cervidae, and from all indications the Hsanda Gol is as old as the first appearance of *Leptomeryx* in North America. As to whether *Eumeryx* is placed in the Cervoidea or Traguloidea is more or less arbitrary but recognition of its pre-cervoid characters is quite important—upper canine developed as tusk, slight traces of Palaeomeryx-fold, no trace of posterior rib on upper molars, inner crescents of lower premolars "nearly as in *Blastomeryx*" (Matthew and Granger, 1925) and metapodials united into cannon-bones but with distal keels not extended over the dorsal surface (the last character is more like an advanced tragulid). Matthew and Granger recognize *Eumeryx*—"as representing a stage of ruminant evolution intermediate between *Leptomeryx* and *Blastomeryx*[1] in the structure of teeth and feet, somewhat more progressive in premolar construction than *Amphitragulus* and *Prodremotherium*"—If, then the Hsanda Gol belongs in the Lower Oligocene the direct traguloid lines giving rise to the Cervoidea may not include *Leptomeryx*. Along other lines of descent *Prodremotherium, Bachitherium, Gelocus* or *Lophiomeryx* may have given rise to the Bovoidea but to date no intermediate forms have been found in the Lower Miocene.

[1] At that time Matthew considered species now included under *Parablastomeryx, Blastomeryx* and *Longirostromeryx* as members of Cope's *Blastomeryx*.

PALAEOMERYCIDAE Lydekker 1883.

The genus *Palaeomeryx*, from which this family name was taken, was described in 1834 by H. von Meyer. It was based on parts of lower jaws and teeth from a Miocene locality near Georgensmund, Bavaria. Though other teeth and mandibles were subsequently recorded from other Old World Miocene faunas it was one hundred and five years later that the first evidence appeared on the nature of the horns in this animal. Dr. C. C. Young discovered, and P. Teilhard de Chardin (1939) described, horns and dentitions from the Shantung Miocene of China which indicate that the horns called *Lagomeryx* may belong to *Palaeomeryx*. That these horns and jaws from China belonged to a given individual cannot be proven by this discovery but no other cervoid-like remains occur in the deposit and in Teilhard's words—"If they had been found in a European site, the above described jaws would, without any hesitation, be determined as *Palaeomeryx*." *Lagomeryx* horns and *Palaeomeryx* dentitions occur in the same European faunas and their synonymy had been suspected (Roman and Viret, 1934).

The discovery in China led Teilhard to suggest that—"a new and special family ought to be erected for *Lagomeryx*, *Procervulus* and other Cervids (with non-deciduous antlers) of the Old World Miocene." Pilgrim (1941), in his admirable paper on fossil types of horns, agreed with this thought. He proposed the name Lagomerycidae and provisionally included the multiple tined *Climacoceras africanus* MacInnes (1936) from the Kavirondo Miocene of Africa.

In view of the probable synonymy of *Palaeomeryx* and *Lagomeryx* it would seem advisable to retain the name Palaeomerycidae. Though Lydekker (1883, pp. 172-173) used the name in connection with an upper molar, *Propalaeomeryx sivalensis* from India, which may be a giraffid, his connotation was clear. He was attempting to show its affinities with the palaeomerycids of the European Miocene and the family name was used to disclose that supposed relationship. As used here the family has a much broader scope.

The cranium of *Palaeomeryx* is still unknown, but the large premolars and other dental characters seem to place the genus near the ancestry of the giraffes on the one hand and perhaps not too far removed from the North American Miocene *Dromomeryx* on the other and its horns are suggestive of cervid antlers. In view of our present knowledge the family may well

be used to include not only Old and New World non-antlered cervoids, but also included should be the hornless types some with stronger giraffid and others with conspicuous cervid affinities.

The Old World genera with forked horns and the American genera with pointed, bulbous or flat tipped horns may be conveniently divided into two subfamilies Palaeomerycinae and Dromomerycinae but it is difficult to know where to place the hornless genera. In all probability they do not represent a taxonomic unit in themselves but each genus will eventually find its proper location in one of the above subfamilies or possibly in the Moschidae when its relationships are clearly understood. The Palaeomeryx-fold lost its distinctness as a family character of the Palaeomerycidae when Schlosser (1924, p. 75) directed attention to its presence in the lower molars of *Capreolus loczyi* (Kormos) a member of the Cervidae from the Pliocene of Hungaria. Then, too, in most genera here assigned to the family the fold is missing.

GEOLOGICAL RANGE OF NORTH AMERICAN PALAEOMERYCIDAE.

Machaeromeryx—Upper Harrison—ARIKAREEAN.

Parablastomeryx—Rosebud; Upper Rosebud; Lusk, Lower Harrison; Thomas Farm; (Bridgeport; Observation Quarry; B Quarry; West Cherry County)—ARIKAREEAN. Antelope Valley; Virgin Valley—HEMINGFORDIAN. Burge—CLARENDONIAN. Xmas and Machairodus Quarries—HEMPHILLIAN.

Blastomeryx—?Garvin Gully—ARIKAREEAN. Sheep Creek; Antelope Valley—HEMINGFORDIAN. Pawnee Creek; (Horse Quarry, Devil's Gulch); Santa Fe; (North Santa Clara River;[2] Santa Cruz; Santa Clara Canyon);[2] Lower Snake Creek; (Midway; Elliot Ranch; South of Logan, Montana); Niobrara River—BARSTOVIAN.

Longirostromeryx—Kilpatrick Pasture Quarry 7, Upper Snake Creek; (Willow Creek; Quinn Ranch; Horsethief Canyon; Bear Creek); Burge; Clarendon; Little White River; Big Spring Canyon—CLARENDONIAN.

Aletomeryx—Lower Harrison; (B Quarry; Bridgeport)—ARIKAREEAN. (Antelope Creek; Barbour-Hemingford Quarry; Marsland; 15 miles northeast of Marsland)—HEMINGFORDIAN.

[2] Called *Longirostromeryx blicki* by Frick: 1937, pp. 224, 234-236, fig. 22A, F:A.M. 31784, p. 221; fig. 23, F:A.M. 31398, p. 222.

Dyseomeryx—(=Syn. *Sinclairomeryx*)—Sheep Creek; (Thompson Quarry; Thistle and Long Quarries; Gin Quarry)—HEMINGFORDIAN.

Rakomeryx—Green Hills, Barstow; Yermo, Mojave Desert—BARSTOVIAN.

Matthomeryx—(Observation Quarry)—ARIKAREEAN.

Drepanomeryx—Sheep Creek[8]—HEMINGFORDIAN.

Barbouromeryx—(Bridgeport; Quarry B; 11 miles southwest of Marsland)—ARIKAREEAN. (Antelope Creek)—HEMINGFORDIAN.

Dromomeryx—(Observation Quarry)—ARIKAREEAN. (Thomson, Greenside and Long Quarries); Sheep Creek; Skull Spring; Mascall—HEMINGFORDIAN. Deep River; Pawnee Creek; (Echo Quarry)—BARSTOVIAN.

Bouromeryx—(Observation Quarry)—ARIKAREEAN. (Greenside Quarry) = Sheep Creek—HEMINGFORDIAN. (Echo Quarry) = ? Lower Snake Creek; Madison River; Pawnee Creek—BARSTOVIAN.

Cranioceras—? Virgin Valley—HEMINGFORDIAN. Pawnee Creek; (Lower Madison Valley; Santa Cruz); Santa Fé; Nenzel; Lower Snake Creek; (Horse Quarry; Devil's Gulch; Survey Quarries); Niobrara River—BARSTOVIAN. (Spring Canyon); Upper Snake Creek, in part; Clarendon—CLARENDONIAN. Leptarctus Quarry—HEMPHILLIAN.

Pediomeryx—Norris Canyon, possibly Siesta; ?Big Spring Canyon —CLARENDONIAN. (J. D. Rankin Quarry); Wray; Optima; Hemphill—HEMPHILLIAN.

The above list is, primarily, a compilation, but an attempt is made to indicate the geological age of the different faunas and occurrences. Those in which the fauna and stratigraphic position is not definitely known by the author (listed by Frick 1937) are enclosed in parentheses. The identification of three specimens known to the author are questionable and these occurrences are preceded by question marks.

The phyletic position of *Pediomeryx* (Stirton 1936) is still questionable. Its short, thick teeth are more suggestive of the giraffes than the deer. If the horns which Frick figured (*Yumaceras figginsi*, 1937, fig. 12A) are correctly associated with the *Pediomeryx* dentition we have here an unusual association of characters. As Frick (1937, p. 142) observed the horns are "not unsuggestive of a very heavy skulled pronghorn," . . . In our series of *Sphenophalos* horn cores from the Thousand Creek (Hemphillian) of Nevada there are specimens that

[8] Matthew (1924, p. 68) records this genus from the Lower Snake Creek.

agree with *Yumaceras* both in size and shape. This indicates that *Yumaceras* (horn) is a generic synonym of the antilocaprid *Sphenophalos* but the lower jaw fragment (Cook 1922, p. 28) as well as the lower jaws on p. 21 are probably referable to *Pediomeryx;* likewise the *? Cranioceras* maxillary and the palaeomerycid lower jaw and M_3 from Big Spring Canyon, South Dakota (Gregory 1942, pp. 400-401) are nearer to *Pediomeryx* than to any known genus, but do not belong to any described species. In all probability *Procoileus edensis* Frick (1937, p. 191) also belong to the genus *Pediomeryx.*

Dromomeryx, Barbouromeryx, Cranioceras and *Bouromeryx* represent a rather compact group in the Palaeomerycidae. Eventually it may be deemed more convenient to include *Barbouromeryx* in the genus *Dromomeryx* and *Bouromeryx* is probably more certainly referable to *Cranioceras.* This group possibly carries back to a common ancestry in *Dremotherium* where they converge with the ancestors of *Palaeomeryx* of the Old World, or, and this appears less likely, they arose from the basal *Parablastomeryx* stem in America. Members of the group may be recognized by a markedly similar construction of the horns, brachyodont teeth with Palaeomeryx-folds on the lower molars.

Barbouromeryx possesses characters which might be expected in the basal line of *Dromomeryx.* This was indicated by Barbour and Schultz (1934) but without some faunal and stratigraphic information its age cannot be at all accurately determined nor can the genus add much to a phylogeny of this kind without such data. For these reasons it has been placed in the *Dromomeryx* line. An animal like this with upper tusks and with short, basal-flanged horns should be accorded generic rank if it is as young as early Barstovian or late Hemingfordian, since there are specimens clearly referable to *Dromomeryx* from older beds in the Sheep Creek and in the Observation Quarry.

Bouromeryx offers a similar problem but is even closer to *Cranioceras* than *Barbouromeryx* is to *Dromomeryx.* If it is not congeneric with *Cranioceras* it certainly is ancestral to it. Frick (1937, p. 127) did not assign the subgenus *Bouromeryx* to any genus but evidently favored placing it in his "Cranioceratinae." The postorbital horns without basal flanges are suggestive of *Cranioceras,* and *Bouromeryx milleri* shows a marked development of the metaconid on P_4 very much as in *Cranioceras. Cranioceras* is distinguished from *Dromomeryx*

primarily by its peculiar superoccipital horn and postorbital horns without basal flanges. A critical study of the Virgin Valley specimens in the University of California collections reveals that they are more like *Cranioceras* than *Rakomeryx*, as listed by Frick (1937, p. 106). This conclusion is supported by the straight horn and presence of Palaeomeryx-folds on the lower molars. Gazin (1932, pp. 82-84, figs. 16-17) evidently was correct in referring the Skull Spring specimens to *Dromomeryx*.

Rakomeryx is difficult to place. The strongly bowed and pointed horns and lower molars without Palaeomeryx-folds offer a distinctive combination of characters. In Frick's (1937, fig. 8, F:A.M.31800) figure there seems to be faint traces of the Palaeomeryx-folds but Frick does not mention them nor do the University of California specimens show the structure. If there is a trace of the fold, this together with the forward direction of the horns and slight basal flange would place the genus near the *Dromomeryx* group. All clearly identifiable remains have been found in the Barstow.

The position of *Drepanomeryx* and *Matthomeryx* are even more uncertain. Frick places them in his "Dromomerycini" division. Both are known from horns with referred dentitions which may or may not be correctly associated. The horns assume a posterior direction from the orbit thus differing markedly from those of *Dromomeryx* with an anterior direction and those of *Cranioceras* which are vertical or nearly so. *Drepanomeryx* and *Matthomeryx* show similarity to *Dromomeryx* but not to *Cranioceras* in the presence of basal flanges. The horns are long and slightly twisted in both animals. In *Drepanomeryx* the distal extremity is flattened whereas in *Matthomeryx* the horns are heavier but not flattened distally. Frick considers *Matthomeryx* as a subgenus of *Drepanomeryx*.

Aletomermyx and *Dyseomeryx* (Syn. *Sinclairomeryx* Frick) are very much alike in the size and shape of their anteriorly curved orbital horns. These horns bear a knobbed distal end somewhat suggesting the pedicle of the living muntjac but among the numerous specimens discovered no one has reported an antler nor is an ossicone present in so far as we now know; but we know nothing of their early Lower Miocene predecessors. How these horns were covered is of course open to question but a covering of skin resembling that in the giraffe is not inconsistent with the evidence. The cheekteeth are high brachyodont types and there is no trace of a Palaeomeryx-fold. Lull

mentions two lacrymal foramina within the orbital rim of *Aletomeryx*.

Blastomeryx and *Longirostromeryx* were evidently hornless, that is, horns have not been found that would seem referable to these animals. The skulls are not known. The lower jaws and teeth are quite distinct as may be seen from the table of comparative characters. *Longirostromeryx*, the youngest genus, possesses higher crowned teeth and a greater reduction in the premolars. *Blastomeryx* evidently gave rise to *Longirostromeryx* in the early Clarendonian. Both genera occur in the Burge.

Parablastomeryx ranges from the Arikareean (Rosebud) up to the early Hemphillian where Frick's field parties have found them in the Xmas and Machaerodus quarries in Cherry County, Nebraska. There is no trace of the genus nor a likely ancestor in the John Day, early Arikareean, or late Whitneyan; but Matthew (1908, p. 556) reports one from the Lower Rosebud, Arikareean. The genus differs from *Blastomeryx* and *Longirostromeryx* in their more complicated upper molars, well defined protocones on P^{2-3}, palaeomeryx-folds on the lower molars, less reduction of the premolars and shorter post-symphysial diastema. Possibly there is an intergradation between *Blastomeryx* and *Parablastomeryx* in some early Middle Miocene fauna but no evidence to that effect has been disclosed.

In 1911 Merriam (pp. 278-280) described *Blastomeryx mollis* from Virgin Valley, later other specimens were found in High Rock Canyon also in Nevada. In their dental characters these specimens seem referable to *Parablastomeryx*. Palaeomeryx-folds, unreduced premolars, P^{2-3} with prominent protocones, mandibular ramus curved, are some of the generic characters so clearly displayed. At the same time Merriam figured (1911, p. 284, figs. 64, 66) two kinds of horns the one (fig. 66) with a vertical position over the orbit he referred to *Merycodus* near *furcatus*, the other (fig. 64) with a slight downward curvature and with a marked posterior direction from the orbit he assigned to *Merycodus nevadensis*. Frick's (1937, p. 350) suggestion that the horn shown in Merriam's fig. 66 may represent *Merycodus nevadensis* is probably correct. The only other dentitions with which the second horn might be associated in the Virgin Valley fauna[4] belong to

[4] This fauna includes both the Virgin Valley and High Rock Canyon assemblages.

Parablastomeryx mollis (Merriam). Two other horns found later in High Rock Canyon evidently from one animal display the characters even better than in the specimen figured by Merriam.

These horns are small, averaging about 10 mm. in diameter with the vertical measurement usually exceeding the transverse by one millimeter. Flatness in Merriam's specimen is due to crushing, at least in part. The angle between the horn and the horizontal plane of the cranium is approximately 45°, thus confirming a similar measurement made by Merriam. There is no indication of a burr-like process, but tiny vascular grooves occur on the surface of the horns. The shape of the horns is suggestive of the pedicles in the Asiatic muntjac but the fossils are more decurved and less flattened. The width between the base of the cranium is 22 mm. and the superior edge of the orbit is more protruding than in *Cervulus*.

Other specific characters are noted in the dentition: greater reduction in P_2 and slightly smaller size than in *P. galushi*. The antero-posterior brevity of M_1 in the type is difficult to explain, the three topotypes and one specimen from High Rock Canyon do not agree with the type. Mesostyles on P^{2-3} slightly inside lines drawn between outer points of parastyles and metastyles; external grooves both anterior and posterior to mesostyles on premolars deeper than in *P. galushi*; fossettes not as deep nor as distinct; well defined ridges extending from tip of mesostyles down into fossettes; protocene on P^2 with anterior and posterior grooves. Upper canine slightly larger and a little more curved than in *P. olcotti* (Matthew 1908, p. 538, fig. 2), with posterior edge sharp and anterior edge broadly rounded, also with 11 mm. (length) groove starting 5 mm. below edge of alveolus and extending partially down the inner side of the tusk.

The three known skulls of *Parablastomeryx*, *P. primus* (Matthew), *P. falkenbachi* Frick and *P. gregorii* Frick are hornless. From this evidence it had been concluded that *Parablastomeryx* did not possess horns. It is possible, however, that the three skulls belonged to females. On the other hand it would seem that some horns, if they were borne by the males, should have been uncovered in one of the Great Plains faunas containing these small ruminants. Thus it can only be stated at this time, that the Virgin Valley materials indicate the presence of horns in the species *P. mollis*. Perhaps the species is worthy of

generic designation, but it will probably be less confusing to await more information and a clarification of relationships.

No additional light has been thrown on the relationships of *Machaeromeryx* since Matthew described it in 1926. It will

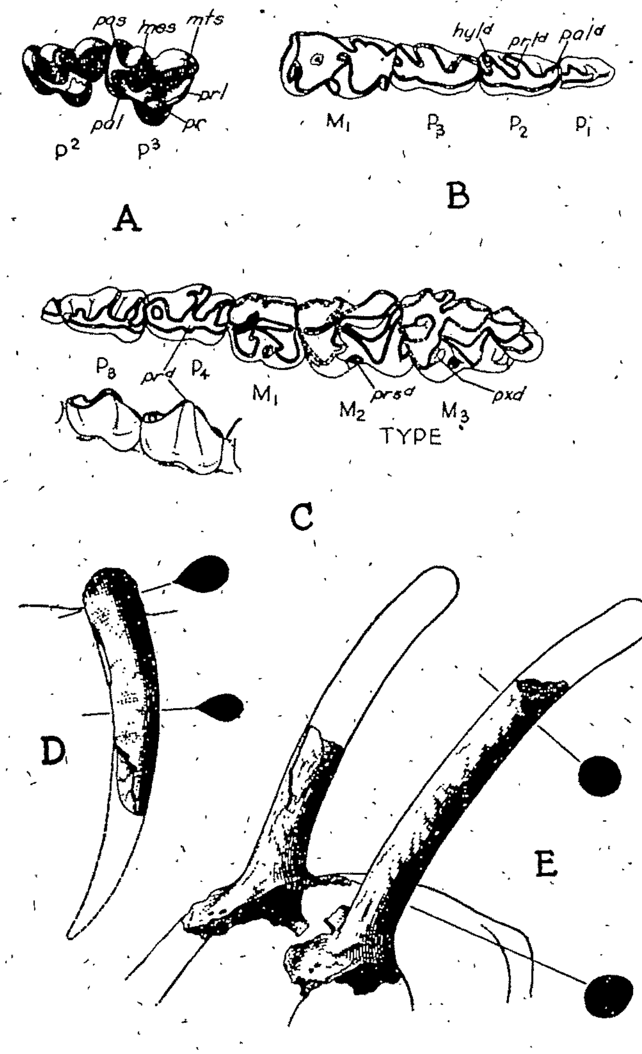

Fig. 1. *Parablastomeryx mollis* (Merriam), Virgin Valley fauna, Hemingfordian, Nevada; Univ. Calif. Mus. Pal. specimens A–C, nos. 11665, 11567, 11564, about one and one-half natural size, Virgin Valley; D, no. 11541, slightly less than three-quarters natural size, Virgin Valley; E, no. 24801, about one-half natural size, High Rock Canyon: *o*-upper canine, *hyld*-hypolophid, *mes*-mesostyle, *mts*-metastyle, *pal*-paraloph, *pald*-paralophid, *pr*-protocone, *prd*-protoconid, *prl*-protoloph, *prld*-protolophid, *prsd*-protostylid, *pxd*-Palaeomeryx fold. Drawn by Owen J. Poe.

be interesting to see the results of a detailed comparison of *M. gilchristensis* White (1941) with species like *Parablastomeryx scotti*, though the Palaeomeryx-fold appears to be missing in the Florida specimen.

According to Stehlin (1914) *Amphitragulus* ranges from the Stampien to the Burdegalien. These are the approximate equivalents of the Whitneyan and late Arikareean in North America. He also records *Dremotherium* from the Aquitanian only and this is about early Arikareean time. Viret (1929, chart between pp. 296-297), however, shows a range for *Amphitragulus* from the Upper Stampien into the early Pontien; he does not give the geological range for *Dremotherium* but describes specimens from Saint-Gérand-le-Puy (Aquitanian). These animals belong to the Cervoidea as that superfamily is defined here and certainly they are older than any of the North American forms. Viret suggests that *Dremotherium* is nearer to the ancestry of the Cervidae than is *Amphitragulus*. If this is true it could be the precursor of all later Cervoidea. *Dremotherium* differs from *Amphitragulus* as follows: Preorbital fossa and lacrymal fenestra; upper orbital rim with greater lateral projection; three instead of four lower premolars; Palaeomeryx-fold is a little more prominent; inflections on lower premolars with less posterior direction.

MOSCHIDAE Gray 1821.

The phylogenetic position of the musk-deer, *Moschus*,[5] is still questionable. Strictly speaking it should not fall within the scope of this short paper but its bearing on the subject at hand seems worthy of some discussion. Only one fossil species is recorded, it was described and figured by Schlosser (1924b, pp. 89-91, pl. 5, figs. 1-9) from the Pliocene of China. Though there are some characters which might be compared a little more in detail with the living animals, Schlosser's description and figures seem clear enough for the generic recognition of the fossil. To date we can only guess at the ancestry of the genus.

Flower (1875, p. 180) has demonstrated rather clearly that *Moschus* is not closely related to *Tragulus*. The general consensus has favored considering it as a primitive member of the Cervidae, but Garrod (1877, pp. 291-292) was not so inclined, he was impressed with its bovid affinities. The presence of a

[5] I am grateful to Dr. W. H. Osgood, Chicago Museum of Natural History for the loan of three *Moschus* skulls.

gall bladder though sometimes found in the Cervidae is by far more characteristic of the Bovidae. Other characters of the soft anatomy seem to be about equally balanced between the two families. The absence of horns[6] and presence of large sabre-like upper canines are found in cervids and palaeomerycids but not in bovids, on the other hand, the smooth enamel surface in

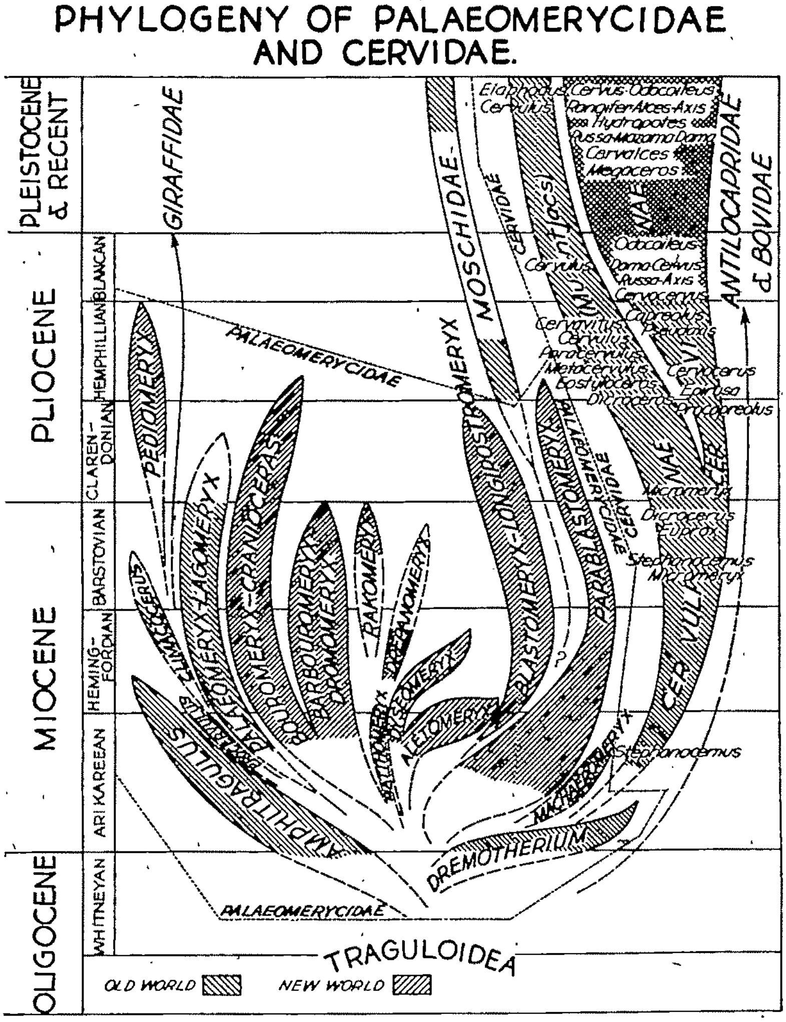

Fig. 2. A phylogenetic chart showing the apparent relationships of the genera of Palaeomerycidae—Genera of the Cervidae are shown in a condensed phyletic plan to illustrate the antiquity of antlered forms. The family Moschidae is included but its phyletic position is not known. Drawn by Owen J. Poe.

[6]The horns of giraffes are quite different from those in the deer and the bovids.

the cheekteeth finds its greatest similarity in the bovids. Brachyodont teeth are found in both groups. In the retention of vestigial metacarpals II and V and the presence of phalanges fore and aft we are again confronted with cervid and palaeomerycid characters, but variable characters like these based on vestigial parts are likely to be of minor significance in differentiating higher taxonomic units. The single lacrymal foramen within the orbit is more common to the Bovoidea though here again there are exceptions; in *Bison*, *Tragelaphus*, *Oreas* and *Antilocapra* the foramen is cervid-like. On the other hand, it is either absent or vestigial in the giraffes. Unfortunately Frick does not mention the structure in his study of the horned ruminants.

It might be worth while to list some of the most conspicuous characters of the skull and mandible: nasals long and narrow and of more or less equal width throughout; nasal in wide sutural contact with the premaxillary; facial vacuity small; no lacrymal fossa; one lacrymal foramen within (not on) the orbital rim; posterior narial chamber not completely divided by vomer; bulla not inflated; external auditory meatus directed postero-dorsally. Canines long, bowed laterally, and slightly decurved; surface smooth, without posterior serrations. Cheekteeth hypso-brachyodont, with smooth enamel surface. No trace of P^1. P^2 greatly reduced, parastyle missing, or vestigial, deep, wide groove between mesostyle and metastyle. P^3 cerviform, small fossette formed in posterior part of tooth by thin crest connecting ectoloph and inner crescent, distance between mesostyle and metastyle relatively and actually much shorter than in *Parablastomeryx galushi*. P^4 cerviform and with no traces of inner cingulum. Molars without complicated connections and crochets in the fossettes, protoloph and metoloph connected by tiny crochet; no traces of inner cingulum or protostyle. In the lower teeth the most conspicuous differences from *Parablastomeryx* are: anterior fossettid narrow, talonid on P_4; absence of mesostylid on molars and development or tendency to develop a labial spur on metaconid, no Palaeomeryx-fold.

It seems clear from the considerations above that *Moschus* is referable neither to the Bovoidea, the Giraffidae, nor the Cervidae as we know these groups today, but its broader relationship to them is apparent. It fits somewhere into the Cervoidea + Bovoidea complex. Perhaps it belongs with the Palaeomerycidae and arose from *Blastomeryx* or from a com-

mon ancestor with *Blastomeryx* earlier in the Lower Miocene. Matthew (1908, p. 546) states—"that its [*Parablastomeryx primus*] structural resemblance to *Moschus* is greater than to any other living genus." The dentition of *Blastomeryx* is even closer to that in *Moschus*. Of course the possibility of its ancestry extending back to *Dremotherium* or even *Amphitragulus* of Europe must not be overlooked. Certainly there is no known evidence to exclude these possibilities and the broad similarity of the genera offers much in its favor. Such features as the smooth enamel surface of the cheekteeth and the specialized feet in *Moschus* could have been acquired since it diverged from its early Miocene ancestry. These and other differences in the cheekteeth and in the absence of a detailed comparison between the skulls of the known *Parablastomeryx* and *Moschus* make it unsatisfactory to include the Recent genus in the Palaeomerycidae at this time.

CERVIDAE Goldfuss 1820.

It is not the purpose of this paper to discuss the intergeneric relationships of the Old World Cervidae. Information on the different genera may be had from papers written by Bohlin (1937), Colbert (1936-1940), Dehm (1937), Filhol (1891), Haupt (1934), Khomenko (1913), Mac Innes (1936), Mayet (1908), Pilgrim (1941a, 1941b), Schlosser (1924a, 1924b), Stehlin (1914, 1928, 1935, 1937, 1939), Teilhard de Chardin (1939), Teilhard de Chardin and Trassaert (1937), and Zdansky (1925). In reviewing these papers it is clear that antlered cervids carry back into the Burdegalien of the Old World (*Stephanocemus*) and at that time show no clear intergradation with earlier genera. The Old World palaeomerycids *Palaeomeryx*, *Procervulus* and *Climacoceras* with palmate-tined, two tined, and multiple tined horns without burrs seem to approximate the Cervidae more closely than do the North American genera; on the other hand it has been pointed out elsewhere that the large premolars of *Palaeomeryx* are somewhat suggestive of the late Miocene and early Pliocene giraffes. The complicated antlered deer (Cervinae) evidently arose from the Miocene cervids through animals like *Cervocerus* Khomenko in the late Miocene or early Pliocene. There is no record of true deer in North America until the Upper Pliocene[7] (San Joaquin clay).

[7]*Procoileus edensis* Frick (1937, p. 191, fig. 20, F:A.M. 31772 from the Mount Eden fauna (Middle Pliocene) of Southern California is probably closely related to *Pediomeryx*).

TABLE I. Comparative Characters.

	Horns	Upper Premolars	Inflections on Lower Premolars	Metaconids	Mesostylids
Amphitragulus	hornless	P^4 cerviform, ? without protoloph crochet; P^{2-3} slightly elongate, not cerviform, with prominent protocones	flexids open lingually, but with tendency to open posteriorly on P_4	not formed, but lingual ends of protolophids on P^4 expanded (P_1 present)	present but not prominent
Dremotherium	hornless	P^4 cerviform, with protoloph crochet; P^{2-3} slightly elongate	flexids open lingually	not formed, but lingual ends of protolophids on P_4 expanded (P_1 present)	only faintly developed
Machaeromeryx	hornless	P^4 nearly cerviform; P^{2-3} elongate, not cerviform	flexids open lingually, but with one posterior flexid	not developed nor with lingual expansion of protolophids	?
Parablastomeryx	horned? postorbital, small, posteriorly directed, slightly decurved	P^4 cerviform, with protoloph chochet; P^{2-3} slightly elongate, not cerviform; with prominent protocones	flexids open lingually	not developed, but lingual ends of protolophids on P_4 expanded	present but not prominent
Blastomeryx	? hornless	P^4 cerviform; P^{2-3} slightly elongate, not cerviform	flexids open lingually	not developed, but lingual ends of protolophids on P_4 expanded	present but vestigial
Longirostromeryx	? hornless	P^4 cerviform; P^{2-3} reduced, not cerviform	flexids open lingually	not developed, but lingual ends of protolophids on P_4 expanded	vestigial or absent

Palaeomeryx-Fold	Posterior Lobe on M_3	Height of Crown of Cheek Teeth	Postsymphysial Diastema	Horizontal Ramus	Upper Tusk
absent	complete loop	brachyodont	medium	curved	present
absent	complete loop	brachyodont	short	curved	present
? absent	? single crest	hypso-brachyodont	medium	slightly curved	present
present	loop formed by heavy outer crescent and short anterior inner cusp or by two crescents	brachyodont	short	usually slightly curved	present
absent	complete loop	brachyodont	medium	straight or slightly curved	?
absent	complete loop	hypso-brachyodont	long	straight or slightly curved	?

TABLE I. Comparative Characters—Continued.

	Horns	Upper Premolars	Inflections on Lower Premolars	Metaconoids	Mesostylids
Aletomeryx	postorbital, slight, nearly erect but slightly curved forward	P^4 cerviform, but relatively wide labially; tendency to divide fossette; P^{2-3} not elongate nor cerviform	flexids open lingually	not developed, but slight lingual expansion of protolophids on P_4	only a remnant
Dyseomeryx = (Syn. Sinclairomeryx)	postorbital, medium length and size strongly curved forward	P^4 cerviform, but relatively wide labially; tendency to divide fossette; P^{2-3} not elongate nor cerviform	flexids open lingually	not developed, but slight lingual extension of protolophids on P_{3-4}	present but not prominent
Rakomeryx	supraorbital, tilted anteriorly and strongly bowed, slight basal flange	P^4 cerviform with prominent mesostyle; P^{2-3} slightly elongate	flexids open lingually	not developed, but slight lingual extension of protolophids on P_{3-4}	present
Matthomeryx	supraorbital, tilted backwards, not expanded distally, with basal flange	?	?	?	?
Drepanomeryx	supraorbital, directed posteriorly, strongly bowed inwardly, shafts slender with tips expanded, with basal flange	?	?	?	?
Barbouromeryx	postorbital, short, heavy, suggestion of basal flange, slight forward direction	P^4 cerviform, with separation of small fossette; P^{2-3} slightly elongate not cerviform, with prominent protocones	flexids open lingually	metaconoid nearly closing fossettid on P_4	prominent

Paleomeryx-Fold	Posterior Lobe on M_3	Height of Crown of Cheek Teeth	Postsymphysial Diastema	Horizontal Ramus	Upper Tusk
absent	loop formed by prominent outer crescent and small anterior inner cusp	hypso-brachyodont	short	curved	present
vestigial or absent	loop formed by prominent outer crescent and small anterior inner cusp	hypso-brachyodont	medium	curved	absent
absent	loop usually open, formed by prominent outer crescent and large trenchant inner cusp	brachyodont	medium	curved	?
?	?	?	?	?	?
?	?	?	?	?	?
present	loop formed by prominent outer crescent and small anterior inner cusp	brachyodont	medium	curved	? present

TABLE I. Comparative Characters—Concluded.

	HORNS	UPPER PREMOLARS	INFLECTIONS ON LOWER PREMOLARS	METACONOIDS	MESOSTYLIDS
Dromomeryx	postorbital, elongate heavy, anteriorly bowed, blunt tip, with basal flange	P^4 cerviform, with prominent mesostyle; P^{2-3} slightly elongate	flexids open lingually	metaconoid sometimes closing fossettid on P_4; lingual expansion of protolophids on some P_3s	prominent
Bouromeryx	postorbital, moderately elongate, heavy, no basal flange [association with dentitions questionable]	?	flexids open lingually but one nearly posterior in direction	metaconoids or strong lingual expansion of protolophid on P_4; lingual expansion of protolophid on P_3	prominent
Cranioceras	postorbital, straight, heavy; supraoccipital, medium length, slightly curved forward	P^4 cerviform, with prominent mesostyle; P^{2-3} slightly elongate	flexids open lingually	metaconoid nearly closing prefossettid on P_4; lingual expansion of protolophid on P_3	prominent
Procervulus	two tined; without burr	?	?	?	?
Climacoceras	multiple tines on one shaft; without burr	?	?	?	?
Palaeomeryx=(Syn. Lagomeryx)	palmate-fork with as many as five sharp tines; relatively long shaft without burr	P^4 cerviform, with heavy mesostyle; P^{2-3} relatively heavy and massive	flexids open lingually (Premolars massive)	not developed, lingual expansion of protolophids on P_4	prominent
Pediomeryx	?	P^4 cerviform, with heavy mesostyle; P^3 nearly cerviform but not as compressed anteroposteriorly as in P^4; both teeth with protoloph [illegible]	flexids open lingually	metaconoid closes prefossettid on P_4 (P_2 considerably reduced)	vestigial

Palaeomeryx-Fold	Posterior Lobe on M_3	Height of Crown of Cheek Teeth	Postsymphysial Diastema	Horizontal Ramus	Upper Tusk
present	loop usually complete formed by prominent outer crescent and large trenchant inner cusp	brachyodont	medium	curved	absent
present	loop formed by prominent outer crescent and small anterior inner cusp	brachyodont	medium	curved	?
present	loop sometimes open formed by prominent outer crescent and large trenchant inner cusp	brachyodont	medium	curved	absent
absent	?	?	?	?	?
?	?	?	?	?	?
present	loop complete	brachyodont	short	curved	? present
absent	single outer crescent, or outer crescent and anterior lingual cusp	brachyodont	?	straight	?

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FOSSIL IMPRINTS OF UNKNOWN ORIGIN:

BARNUM BROWN AND H. E. VOKES.[1]

II. FURTHER INFORMATION AND A POSSIBLE EXPLANATION.

ABSTRACT. Additional material has indicated that the form originally described in this Journal in a note bearing the above title is rather widely distributed in the upper part of the Mowry shale in Montana and Wyoming. It thus seems to have stratigraphic significance, and is here named *Asterichnites octoradiatus* new genus and species. A review of the evidence furnished by all known material, correlated with other data permits the suggestion that these imprints may have been formed by some type of dibranchiate cephalopod.

An appendix contains the results of an examination, by Dr. Valentine of Brooklyn College, of the sediments in which the imprints are found and permits an explanation for their preservation.

IN a recent report (Vokes, 1941), the junior author published a short description of an unusual type of fossil imprint and requested suggestions as to its possible origin. A number of such suggestions were received, but none of them, in his opinion, were such as to fulfill the requirements obviously made by the nature of the fossil itself, or which did not meet with fundamental objections based on the nature of the animal types proposed, at least insofar as the animal types suggested are known in their modern development.

In addition to these suggestions, photographs of very similar markings were forwarded by Dr. John B. Reeside, Jr., of the United States Geological Survey. These had been taken by Dr. W. G. Pierce, of the Survey, during the 1941 field season. The fossils were found in sandstone beds in the Mowry shale, at a "point several miles northeast of Cody, Wyoming, where a new irrigation canal crosses the Mowry outcrop."[2] The fossils are apparently identical with those that had been described earlier, but there are certain peculiarities in some of the imprints which merit attention and will be discussed below.

Finally, while engaged in field work in Montana during November, 1941, the senior author secured two large slabs containing a number of the imprints. These have since been

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior.

[2] Letter from Dr. Reeside, dated November 28, 1941.

prepared in the laboratory and were studied during the preparation of this report.

OCCURRENCE.

Geographic. The specimen originally described and figured was obtained through Mr. Oscar T. Lewis from a locality about fifteen miles southwest of Billings, Montana. At the time that he forwarded the specimen, Mr. Lewis stated that they were known from two localities about three miles apart in the same general region and from the same geological horizon. The two large specimens secured by the senior author are from the same general area, but it is not certain that the locality ("on the farm of Ora Hartley, Sec. 31, T. 2S., R. 26E.") is identical with those mentioned by Mr. Lewis. In addition to these specimens, there is in the collections of the American Museum of Natural History another obtained from Mr. A. E. Perry, of Winnett, Montana. This was found on the drainage of the Musselshell River, near the Cat Creek Anticline, in Montana. These, together with the occurrence near Cody, Wyoming, constitute the present known distribution of these imprints. They are, however, so widely separated and so generally numerous at these localities as to leave no doubt but that they were formed by some distinctive and abundant type of organism.

Stratigraphic. All of the imprints occur in sandy members of the Upper Cretaceous Mowry shale. This is true of the specimens photographed by Dr. Pierce near Cody, Wyoming, (see quotation from Reeside letter, above) and of the specimen from the Musselshell region secured by Mr. Perry. Concerning the stratigraphic horizon of his find Mr. Perry states that specimens which he had sent to the United States National Museum contained fish plates, concerning which Dr. Resser wrote (to Mr. Perry): "The fish plates . . . are known as *Leucichthyops vagans* Cockerell and *Holcolepis transversus* (Cockerell), typical species of the Mowry formation of the Colorado Group." Mr. Perry also reported that his fossils occurred "in the extreme upper part of the formation" and are overlain by a "shell sandstone" [presumably the Frontier sandstone].

The specimen originally described was said by Mr. Lewis to have come from "a lower member of the 'Colorado Shale' at the top of a sand formation, possibly the Mowry(?)." The two slabs secured by the senior author are from the same general

region. A geological map of the area by Knappen and Moulton (1931, Pl. 1) confirms the Mowry age of this material.

No identifiable fossils have been found in association with any of the specimens examined, although all of them show numerous other, non-identifiable markings, and the matrix of the larger slab secured by the senior author contained fish scales of a herring-like type. These, together with a single unidentifiable fragment of an ammonite found in the same horizon near the quarry from which the slabs were removed, indicate that the imprints were formed in a marine environment.

Owing to the fact that these peculiar imprints may prove of value in stratigraphic studies, inasmuch as they are widely distributed in Montana and Wyoming and seem to have a restricted geologic range, being at present known only from the upper part of the Mowry shale, it has seemed desirable to give them a scientific name for future reference. They are, therefore, here designated as ***Asterichnites***, in allusion to the stellate nature of the imprints, with *A. octoradiatus* as the type and only known species. No similar or comparable forms are known.

Asterichnites octoradiatus, n. gen. and n. sp.

Plates 1, 2, 3.

DESCRIPTION OF THE SPECIMENS.

1. Specimens from near Billings, Montana:

A. *Original Specimen*: Holotype, American Museum, No. 25384. (Pl. 2, fig. 1)

This specimen consists of a small block containing one complete imprint and a portion of a second one at its edge. The complete imprint consists of eight sharp grooves radiating from a central, unmarked area. The total diameter of the specimen is 64 mm., the grooves being each 16 mm. long, 2 to 3 mm. wide, and 3 to 4 mm. deep. They are sharp and clear-cut and seem to have been made by some relatively hard and pointed object similar to a claw. At the inner end of each of the grooves is a little pile of matrix which is undoubtedly composed of the material scooped up during the formation of the groove and indicates that the grooves were formed by the contraction toward the center of the eight radiating parts of whatever structure formed them. The fact that the material removed from the grooves remains as little upraised piles seems

to indicate that the central part of the object was raised above and not in immediate contact with the sea floor at the time that the movement resulting in the formation of the grooves was completed.

The matrix of the specimen is a fine-grained, light gray sandstone or "siltstone" in a stratum about three inches thick. The stratum is finely to coarsely laminated, the laminae showing marked evidence of cross-bedding and current action.

B. American Museum paratype No. 25383: (Pl. 1, fig. 1).

This specimen represents the larger of the two slabs secured by the senior author. It is 74 inches long and 21 inches wide and bears on its surface 13 of the stellate imprints. Of these, a series of eight seems to have been made by one individual, while three others seem to be part of another series made by a second individual. All of these imprints are identical in their general characteristics with those of the original specimen. They vary in size, the small group of three imprints having a greatest diameter of 75 mm. with the central area being 35 mm. wide. They are the largest that have been observed. The series of eight imprints vary in diameter from 59.6 mm. to 66.8 mm., four of them being 66 mm. across. The distance between the various markings also varies within wide limits. The shortest distance from the center of one imprint to the center of the next adjoining one in the series is approximately 90 mm., while the greatest distance is approximately 195 mm. Beginning at the upper end of this series as shown in Plate 1, fig. 1, the following are the distances (in millimeters) between the centers of the adjoining imprints: 90, 115, 145, 163, 175, 184, and 195.

On this specimen the small piles of sand at the inner ends of the grooves are not as well preserved as they are on the original specimen, but their presence is clearly indicated on some of the imprints, notably on the first of the above series of eight and on the outermost of the series of three. Their poor development on the other markings seems to be due only to accident of preservation.

One noteworthy feature observed in these two series of markings is that the lateral grooves in each series are not strictly symmetrical in their shape. In general one side of the groove is much more acutely incised than the other, in some cases it even somewhat overhangs the bottom of the groove itself. In such examples the opposite side of the groove is always more

gently sloping with relation to the surface of the slab than it is when the two sides of the groove have an approximately equal angular relations to the surface.

The matrix of this specimen is a dark gray to black, fine-grained, hard "siltstone." The rock is finely laminated showing extensive cross-bedding on a small scale. There are a number of thin, discontinuous lenses of light gray, coarser sandstone irregularly distributed throughout. The surface of the specimen which is weathered to a grayish-brown color is somewhat irregular with inconspicuous, low ridges. These suggest ripple-marks, but are too poorly developed to furnish evidence as to the manner of their origin, though they do add corroborative evidence to the physical factors observable in the rock itself suggesting shallow water deposition.

C. American Museum paratype No. 25382. (Pl. 1, fig. 2).

This, the second specimen secured by the senior author, is 53 inches long and 16 inches wide. It, too, shows 13 stellate imprints upon its surface. Of these there is one series of eight imprints which seems to have been made by one individual, while the remaining five seem to represent a portion, at least, of another series made by a second example.

The imprints in the first series are identical with those described above, the average diameter of the imprint being 66 mm., while the central area is approximately 25 mm. across. The distance between the centers of adjoining imprints, however, varies much more widely than do those on specimen 25383; beginning at the left of this series, as shown on Plate 1, fig. 2, the approximate distance (in millimeters) between the centers of adjoining imprints is as follows: 30, 163, 170, 128, 225, 200, 265. As with the imprints of the series shown on the specimen described above, the lateral grooves of the present series are also not strictly symmetrical in shape, being in general more sharply incised on one side than on the other.

The imprints of the second series on this slab differ markedly from those which have been described above in that the eight radial markings are, for the most part, not simple, incised grooves, but consist rather of relatively broad, shallow areas bordered by subparallel, incised lines. This is particularly true of those which are lateral with respect to the trend of the series as a whole. In general, the incised marginal lines are slightly farther apart near the outer edge of the specimen and become almost parallel along the inner half of their length. In

the uppermost of the five imprints of this series, however, they tend to approach each other throughout their entire length, forming elongate, narrow "V" shaped marks.

It seems to be significant that these markings are not as deeply incised as those which form distinct grooves. In this connection the second imprint (from the bottom) of this series is of particular interest in that the lateral markings on the left side are similar to those noted immediately above, while those on the right are more deeply incised and tend to form typical grooves as do also the markings which are parallel with the trend of the series as a whole. This seems to offer some suggestions as to the nature of the structures which are responsible for the imprints and will be discussed in detail below.

The matrix of this slab is similar in every detail with that of specimen No. 25383, except that its upper surface is of a darker brown color and is somewhat more irregular, so that the ripple-like waves are not readily observed.

2. Specimens from near Cody, Wyoming: (Pl. 2, fig. 2; pl. 3, figs. 1, 2).

The following notes are based upon the three photographs made by Dr. Pierce of the Geological Survey of specimens found in sandstone beds in the Mowry shale at a "point several miles northeast of Cody, Wyoming." One of the photographs shows a large slab on which may be seen twelve of the imprints (Pl. 2, fig. 2). Nine seem to be wholly identical with that originally described, although they are somewhat more deeply impressed and, due to weathering, less sharply defined. Near the bottom of the slab, however, there are three grooves which merit special notice. Here the radii are plumosely marked by short, lateral grooves curved inward toward the central disk. The number of these lateral grooves varies, even on opposite sides of the same radial groove, but there are never more than seven on any one side. The imprints with these plumose, lateral markings seem to be of the same relative size as are the other more characteristic ones on the same slab.

The other two photographs are on a somewhat larger scale. Each show all or part of four imprints, three of which on each block are of the normal type while the fourth shows some development of the plumose lateral grooving. One of the latter (Pl. 3, fig.1), consisting of one-half an imprint preserved on the edge of a slab, is of particular interest in that it combines the two types of anomalies noted above. One portion of the print

consists of sub-parallel, incised lines similar to those on AMNH 25382, while the adjacent radii show the plumose lateral markings.

SUMMARY OF OBSERVATIONS.

As a result of the laboratory examination of 28 individual imprints, together with a study of photographs showing 20 others, the following observations may be recorded.

1. The normal imprint consists of eight grooves, appearing as radii around a central disc which is always unmarked except for the presence of small piles of sandy matrix at the inner terminus of the grooves. These piles are composed of the material scraped up during the formation of the grooves.

2. The grooves radiating from each disc are variable in all dimensions. The length of those of the original specimen, which is fully typical in this respect, is as follows (in sequence): 17.7, 16.5, 16.7, 17.3, 13.4, 15.2, 17.5, 17.6 mm. They also vary in width and in depth. It is also noteworthy that in the two series of eight imprints preserved on the large slabs, each of which was apparently made by a single individual, the same variations are to be noted not only in the relative sizes of the radii of each imprint, but also in the sizes of the analogous grooves in each of the imprints of the series.

3. Although the eight grooves of each imprint radiate out from the central disc they are not strictly radial in position. This is well shown if the axes of the radii are projected across the central disc. Then it will be seen that the axes of opposite grooves do not in all cases coincide, nor do they actually meet in the center of the disc. In a number of the examples six of the eight grooves are opposite, while two are offset, the offsetting always being in such a manner that the axes are parallel to each other, never so that the two axes intersect. It is also to be noted that where this condition obtains, the two parallel axes are those most nearly parallel to the direction of progression indicated by the trend of the series of imprints.

4. This direction of progression of the object making the imprints is also indicated by the fact that the grooves of each imprint lateral to the trend of the series as a whole are not always symmetrical in section, being more acutely incised on one side than on the other. In some cases one side of the groove may even overhang the bottom of the groove itself, while the opposite side may show a very gentle inward slope. If this

be interpreted as indicating the axis of the direction from which the pressure was applied to the structure forming the groove, and if it may be supposed that the pressure was applied as a part of a "hopping" movement by the animal responsible for the grooves, then the direction of the movement is clearly indicated.

5. If the above assumptions as to direction of progression are valid the early imprints (in the two large series) are spaced more closely together than are the later ones, almost suggesting an increasing speed of progression before the "take-off."

6. Certain imprints which are not as deeply incised as most show relatively broad, shallow areas bordered by sub-parallel incised lines instead of the typical grooves. In all cases these tend to be most widely spaced at their extremities and to approach one another as they near the central disc.

7. A number of the radii, generally also not as deeply incised as the most typical types, also exhibit a series of plumosely arranged lateral lines which curve inward toward the central disc.

CONCLUSIONS AS TO NATURE OF ORGANISM FORMING THE IMPRINTS.

The examination of these imprints permits certain conclusions as to the nature of the organism which produced them. The most obvious feature is that it must have possessed eight projections which are essentially radial in position. That these projections were relatively flexible is suggested by the variability in the length of the grooves, especially since the analogous grooves in the series of imprints may vary in their length. Furthermore, the fact that they are incised in the matrix and that there is a small pile of material at their inner terminus clearly shows that they were capable of being stiffened and controlled by muscular action and did not simply rest flacidly on the surface of the sediment.

The indications of a definite direction of progression, together with the fact that the radii are not all directly opposite one another, since those lying in the direction of progression may be slightly offset from a true radial position, strongly suggest that the animal concerned had some form of bilateral symmetry, and it is probable that the apparent radial symmetry was a feature of the structures making the prints rather than of the entire organism.

The presence of the subparallel, incised lines, rather than grooves in some of the imprints and of the plumose lateral lines in these and other prints which are but lightly incised, suggests that the structures forming the grooves were either branching ones or were somewhat elongated, ribbon-like structures possessing relatively stiff projections along the sides and perhaps with a pair at their tips. It would seem possible that these projections could remain separated when the structure was in but light contact with the bottom but would be drawn together and serve to form but a single groove when the resistance of the bottom material was such as to require fairly strong muscular contractions, such as that evidenced in the deeply incised radii.

This suggests that the animal was not a strictly bottom-dwelling form, but rather one whose contact with the bottom was capable of variation. This is more strongly indicated by the fact that the imprints tend to occur in series which begin and end abruptly and without continuation. Two suggestions have been made to explain this feature; either that the animal was a free-swimming form which approached the bottom for feeding or other purposes, or that it was a floating form which "bumped" along the bottom in the trough of a wave but was lifted clear by the crest.

Objections to this latter suggestion seem clearly obvious. The imprints are too clearly cut to have been made by any dragging object, and there is never any simple "drag mark" such as would result from unusually deep wave troughs. Furthermore, the imprints would be expected to be more closely together at the lowest part of the trough rather than at the initial part of the series which would be formed as the animal first slid off the crest of the wave.

In summary, the evidence which can be adduced from the imprints require that they have been formed by a free-swimming animal which probably was of a bilaterally symmetrical type, but which had a (secondarily?) radial symmetry of that structure that actually made the impressions. This structure must have been flexible and elongated, but subject to muscular control, and probably was armed with relatively stiff projections along its sides.

These conclusions as to the probable nature of the animal which formed these imprints eliminate a number of types from consideration and focuses attention on the cephalopods, since they are free-swimming, bilaterally symmetrical animals pos-

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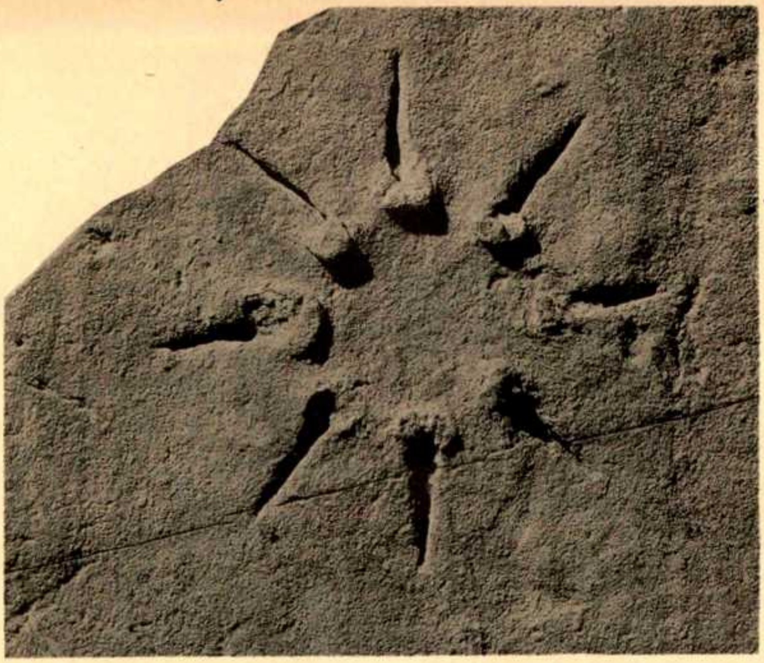
PLATE 1.

Asterichnites octoradiatus, new genus, new species.

(Fig. 1) Am. Mus. Nat. Hist. Cat. No. 25383, (paratype). The slab is 74 inches long and 21 inches wide. Southwest of Billings, Montana.

(Fig. 2) Am. Mus. Nat. Hist. Cat. No. 25382, (paratype). The slab is 53 inches long and 16 inches wide. Southwest of Billings, Montana.



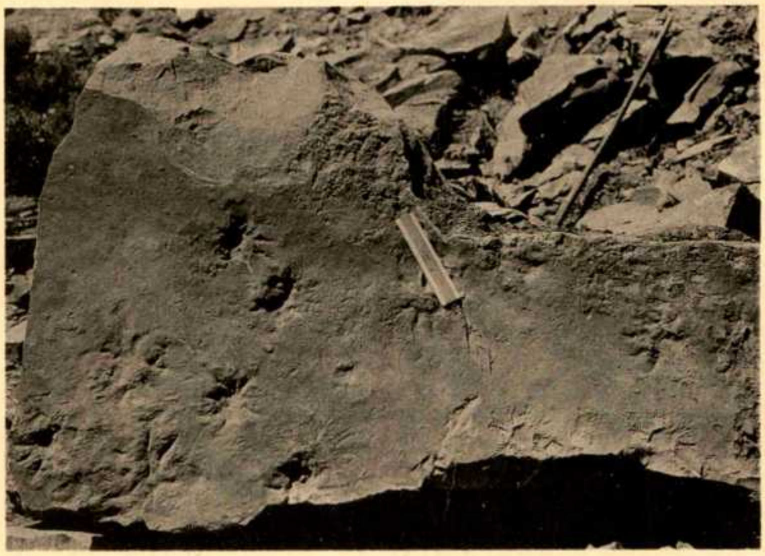


PLATE 2.

Asterichnites octoradiatus, new genus, new species.

(Fig. 1) Am. Mus. Nat. Hist. Cat. No. 25384, (holotype, natural size). Found about 15 miles southwest of Billings, Montana.

(Fig. 2) Field photograph of specimens found northeast of Cody, Wyoming by Dr. W. G. Pierce, U. S. Geological Survey. (Note the plumose markings shown in the lower right of the specimen.)

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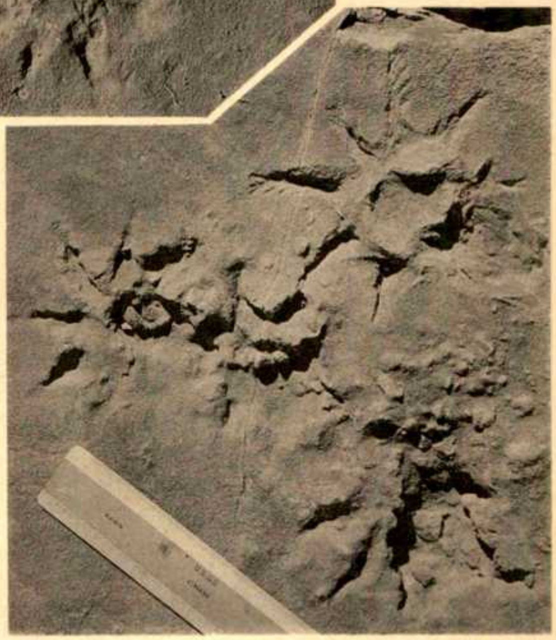

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PLATE 3.

Asterichnites octoradiatus, new genus, new species.

(Figs. 1, 2) Field photographs of specimens found northeast of Cody, Wyoming by Dr. W. G. Pierce, U. S. Geological Survey.

PLATE 4.

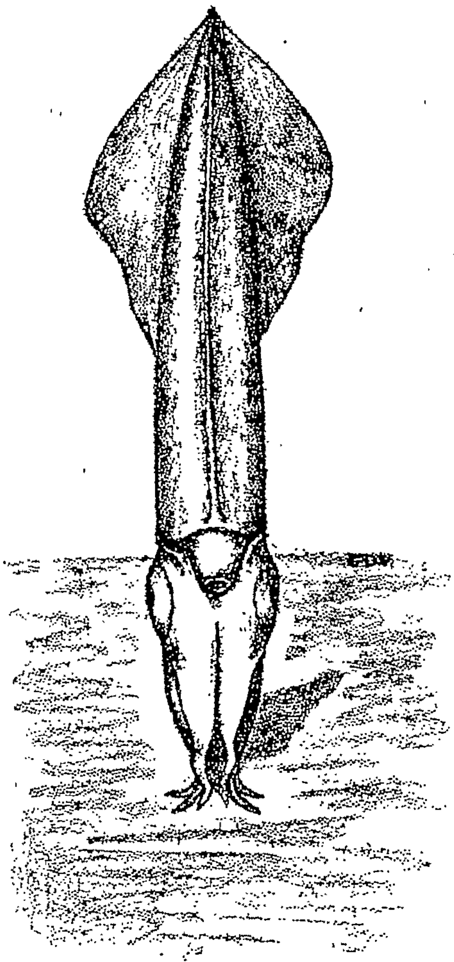
Plesioteuthis prisca (Rüppel).
View (X.75) of the anterior end of a specimen from Eichstadt, Bavaria, (Jurassic) showing preserved imprint of tentacular ring. Compare with specimens of *Asterichnites octoradiatus*. Am. Mus. Nat. Hist. Cat. No. 15471/1.

sessing a radially arranged ring of tentacles about the mouth. Investigations in this group furnished evidence which strongly suggests that the imprints could have been formed by a squid-like type. These dibranchiate cephalopods possess ten tentacles, but two are often highly modified for sexual purposes. Furthermore, the suckers on the tentacles are also often modified to form chitinous hooks, a feature which would give them sufficient strength to scrape out the sediments during the formation of the grooves.

This modification of the suckers may actually have been the primitive condition of the tentacles of these animals. At least it was present in the Triassic, as is shown in specimens figured by Naef (1922), and apparently was widely developed among the belemnites (Crick, 1907). This latter group in the Liassic at least had apparently only six uncinated arms. These facts, together with the discovery among the collections in the American Museum of Natural History of a specimen of a squid from the lithographic stone at Eichstatt, Bavaria, labelled as *Plesioteuthis prisca* (Rüppel) (see Pl. 4) in which there is a clear imprint of eight tentacles lying in exactly the same relative position as are the radii of the imprints, and also, though coincidentally, of almost the same size as would be required of those which formed the fossil markings, strongly suggest a dibranchiate cephalopod origin for the imprints.

There still remains the question as to whether or not the cephalopod would be inclined to approach the bottom at an almost vertical angle when feeding. An examination of the literature relative to modern cephalopods led to the discovery of the observations of Drew (1911) on *Loligo pealii* (Les.). In this work Drew presents a most timely illustration (see text fig. 1) showing the female squid "in the position she assumes as she bounces over the bottom on the tips of her arms just previous to selecting a place for sticking the egg string." In describing this activity, Drew says: "Toward the end of the period during which the string of eggs is held, the animal shows an increasing tendency to turn the body into a nearly perpendicular position to bring and keep the tips of the arms in contact with the bottom . . . . With the arms held quite rigid and the tail fin moving rapidly she goes bounding along on the tips

of her arms, dorsal side foremost, with a movement somewhat similar to the bounces that may be obtained by pushing a lead pencil, held at one extremity and slightly inclined from the perpendicular, over a table. This action is generally repeated



Text Fig. 1. *Lolligo pealii* (Les.). After Drew (1911) showing the female squid "as she bounces over the bottom on the tips of her tentacles."

several times." The position of these animals is identical with that of the one that formed the imprints would have had to assume at the time that they were formed, and the fact that the modern animals do assume this position seems highly corroborative of the deductions based upon the evidence afforded by

the prints themselves. However it cannot be considered as being conclusive evidence, since the modern squids progress through jet propulsion from the siphon, and there is no evidence that the "bouncing" on the tentacles, noted by Drew may not be more apparent than real, and that the actual "bounce" may not be a result of water expelled from the siphon rather than from the contraction of the tentacles. On the other hand it is not certain that tentacular contraction may not enter into the picture during the abnormal activity observed during the egg-depositing period, nor is it certain that it may not have been a factor in the movement of the particular type which formed the fossil imprints.

It must be admitted, however, that while the evidence favoring a dibranchiate cephalopod origin for these imprints is highly suggestive and quite plausible, it is not conclusive.

The problem as to the preservation of these imprints is of considerable interest. The evidence afforded by the depth of the grooves, the delicacy of the plumose markings and the nature of the little piles of sediment at the inner ends of the grooves, strongly suggests that matrix in which they are preserved was relatively soft and unlithified at the time when the imprints were formed. In view of all of the various lines of evidence suggesting a shallow-water environment of deposition, it is necessary to believe that the imprints were subject to almost immediate burial, in order not to have been destroyed by the action of waves or currents.

In taking up the two large slabs described above, the senior author noted that the "track layer" was overlain by a deposit of soft, unctuous, greenish-gray clay which was but a few inches thick. Samples of this clay and of the matrix in which the imprints are found were submitted to Dr. Wilbur G. Valentine of the Department of Geology, Brooklyn College, for examination. The writers are greatly indebted to Dr. Valentine for permission to publish his report on this material. His conclusions as to the volcanic content of these sediments serve not only to confirm the Mowry age of this material, but also afford an explanation as to the methods by which these imprints were rapidly buried and preserved.

REPORT ON SAMPLE OF CLAY AND IMMEDIATELY UNDERLYING ROCK.

By

WILBUR G. VALENTINE.

This report is based upon samples on material supplied by Dr. Barnum Brown of the American Museum of Natural History. One is a sample of unctuous clay; the other, a piece of the rock immediately beneath the clay.

SAMPLE OF CLAY.

INTRODUCTION.

Three kinds of tests were made on the sample of clay:

1. A dry sample was allowed to stand in water.
2. A sample was sent to Prof. Paul F. Kerr of the Department of Geology and Mineralogy at Columbia University for an X-ray diffraction determination of the crystal structure.
3. Several thin shavings were mounted on glass slides to study microscopically the character and refractive index of the constituents.

SAMPLE SOAKED IN WATER.

This sample swelled and cracked. The amount of swelling was not as great as would be expected if the material were a high-grade bentonite. The swelling that did occur leads to the conclusion that the material contains an appreciable amount of the mineral, presumably montmorillonite, that is responsible for the swelling of bentonite.

X-RAY ANALYSIS.

Prof. Paul F. Kerr was kind enough to make the following report:[1]

"As nearly as we can tell from an ordinary molybdenum X-ray diffraction pattern, the clay material that you submitted some time ago is a mixture of kaolinite and quartz. Without chemical data it would be impossible to say whether it is actually kaloinite or anauxite. I think it is reasonably safe, however, to assume that it belongs to the kaolinite-anauxite series."

[1] Personal communication dated May 26, 1942.

This determination does not support the assumption that the material contains a dominant amount of montmorillonite or related minerals, which are the common products of the devitrification and weathering of volcanic ash. It advances the concept that the dominant material is kaolinite or anauxite, usually formed by the weathering of feldspar or other aluminous silicates. If this is true, it would be more logical to explain it as a transported clay rather than the result of alteration of volcanic ash.

MICROSCOPIC EXAMINATION.

Method. This material was not suited to thin-section making, so the microscopic examination was carried out in a different manner. A slightly damp piece of the clay was sliced with a razor blade, producing thin shavings. These were placed on glass slides, covered with other glass slides, and surrounded by different liquids of known refractive indices. In this manner, the refractive indices of the constituents could be determined, and the character of the material could be observed. The shavings were not of uniform thickness, but the edges were thin enough to study.

General character. The greater part of the material is an exceedingly fine flaky (?) aggregate. Some of it has low birefringence, but at least half of it shows yellow interference colors even near the edges of the shavings. In such places, the thickness of the material is probably comparable to that of a thin section. From this birefringence, I conclude that this moderately birefringent portion at least is not kaolinite, but a mineral of the montmorillonite group.

Scattered through the fine matrix are many patches of different appearance and composition. These are small (about 0.1 mm. diam.) and often quite angular. Many of them are greenish brown in color, and appear to be iron-stained serpentine. Occasionally one finds a larger fragment of feldspar or quartz, also quite angular. The feldspar appears to be unaltered.

The refractive index of most abundant constituent of the fine-grained matrix is close to 1.500. When immersed in a liquid having this index, the Becke line is hardly discernible. The refractive indices of some of the clay minerals are:

Kaolinite—1.561 to 1.567
Anauxite—about the same as kaolinite
Montmorillonite—1.500 to 1.520

This part of the study seems to indicate that the bulk of the clay material belongs to the montmorillonite group rather than the kaolinite group.

In this matrix are also many minute grains with distinctly higher indices. These, I judge, comprise about one-quarter of the material. They may be grains of another clay mineral, or of quartz. The former is more probable, as their outlines cannot easily be seen when the surface is in sharp focus.

CONCLUSIONS ABOUT THE CLAY.

The results of the physical tests and the microscopic examination seem to be in opposition to the results of the X-ray diffraction study insofar as the identity of the principal clay mineral is concerned. I conclude that both kaolinite (or anauxite) and a member of the montmorillonite group is present. Although glass shard structures are not clearly demonstrable in the material, I conclude that a large portion of this material was fine volcanic ash of variable composition. The name bentonite or impure bentonitic clay best describes the material.

ROCK IMMEDIATELY BELOW CLAY.

INTRODUCTION.

A standard thin section of the rock which immediately underlies the clay was studied under the petrographic microscope. The purpose of this study was the determination of the character of the rock and the conditions under which it was deposited. It was hoped that this study would determine whether volcanic products were being formed immediately preceding the formation of the clay. If this were true, the conclusion that the clay is partly or wholly of volcanic origin would be supported.

DESCRIPTION.

This rock is a fine silt showing prominent lamination. In the coarser textured layers, most of the grains are less than 0.1 mm. diam., with a few larger grains (some up to 0.5 mm. diam.). The darker layers are finer textured in general, and contain prominent amounts of mica. All grains are highly angular.

The mineral grains are principally quartz and feldspar, the latter usually unaltered microcline or sodic plagioclase. There are many angular fragments of volcanic glass. Most of these

are light colored and probably represent an acid type such as pumice or rhyolite. Others are dark and probably represent andesitic or basaltic fragments. In some layers these glass fragments are more abundant than other constituents. In addition to these constituents are occasional bituminous grains, a few of tourmaline, and some other accessories which were not identified.

The rock seems fresh and unmineralized. There is some serpentine developed from the basic rock fragments. In one place, a minute quartz veinlet was found.

INTERPRETATION.

There is no question that this rock is a fine clastic sediment deposited in water. The conditions of sedimentation were changing periodically as attested by the laminae or thin beds of different texture. These variations were probably due to changes in physical conditions, such as: depth of water; direction and strength of currents; character and amount of material supplied. Only the last of these conditions is of interest in the present study.

The thin section of this rock was compared with one of "volcanic ash shale" from Florissant, Colorado. This latter rock is generally accepted as having been derived in part from volcanic ash. The rock from Montana differs from the Florissant, Colorado, rock in the following details:

1. It is more firmly cemented.
2. It is finer in texture.
3. The laminae do not have as great textural variation.
4. It contains a greater quantity of sharply angular volcanic glass shards (the Florissant rock contains more fragments of rhyolite which are larger and more rounded by water action).

In all other respects the rocks are similar. It follows that the rock from Montana might also be called a "volcanic ash shale."

The question arises as to whether the volcanic ash material found in this rock was derived directly from the atmosphere at the point of deposition, or whether it was carried by streams from distant sources. It would seem that the occasional large volcanic glass fragments in a much finer aggregate were probably derived directly from the atmosphere. It would seem likely also that the sharply angular glass shards were not trans-

ported great distances by water. It is possible that a large proportion of the volcanic glass fragments and the attendant quartz and feldspar grains (which also might be direct products of volcanic action) were deposited in the immediate vicinity and were merely reworked by waves and currents, or washed from nearby land surfaces.

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A NEW IDEA ON CONTINENTAL DRIFT.

J. R. CHELIKOWSKY.

ABSTRACT. The asymmetric arrangement of the earth's surface is a reflection of asymmetry at depth. The Pacific Basin is considered to be a primary basin, and the Pacific sector of the shell immediately above the earth's core is considered to be denser than other sectors. Hence it is subsiding and exerting pressure on the core which is assumed to act like a liquid. The pressure on the core is relieved by a bulging-out action in a direction of easy relief. This explains the ellipticity of the earth's equatorial section. The combined bulging out and subsidence will displace or stretch the sialic crust away from the area of bulge toward the collapsing floor of the Pacific. The earth as a whole is considered to be in isostatic balance at all times—equal moments of momentum.

INTRODUCTION.

ONE of the greatest stumbling blocks to the acceptance of the Continental Drift hypothesis has been the lack of an adequate explanation for the cause of drift. Wegener postulated the drift idea primarily as an explanation for the configuration and distribution of continents and ocean basins. He was not vitally concerned with its cause, and frankly admitted that the cause "is still too much in a state of flux to permit of a complete answer in every detail."[1] The drift concept was merely a working hypothesis for the explanation of certain effects. Hence most of the criticism against the idea has really not been directed at drift at all, but at Wegener's explanation of mountains, climatic changes, and the distribution of fauna and flora on the basis of continental drift. It seems that too much emphasis has been placed on the effects, and too little on the cause. If it can be proved that there are no forces acting on the earth or within the earth capable of shifting continents, then drift is impossible, but if an adequate force can be found, then drift must always be accepted as a possibility.

The idea of drift was probably born with Suess'[2] explanation of the Himalaya arcs. He postulated a southward creep of northern Asia against the hinterland of the Indian Shield to form the mountains. This idea was later expanded by F. B. Taylor[3] into a rather extensive migration of all land masses

[1] Wegener, A.: 1922. Die Entstehung der Kontinente und Ozeane, Braunschweig. Translated by J. Skerl, London, 1924, p. 205.

[2] Suess, E.: 1897-1918. La Face de la Terre, Paris. Translated by E. de Margerie.

[3] Taylor, F. B.: 1910. Bearing of the Tertiary Mountain Belt on the Origin of the Earth's Plan, Bull. G.S.A., Vol. 21.

toward the equator and the Pacific. Wegener's idea on continental drift followed. Three possible forces were suggested by him:[4]—(1) the equatorward force on floating bodies discovered by Eötvös; (2) The westward tidal force worked out by Schwartz and others; and (3) a downhill gravitational force away from Helmert's 1915 major equatorial axis located at 17° W Longitude. In 1926 Daly published his Mobile Earth in which he brings to light his sliding idea. It was Wegener's suggestion of movement away from the earth's major axis and Daly's Pacific sliding, together with his explanation for the asymmetry of the earth's face,[5] that helped to crystallize the idea set forth in this paper.

SIZE, SHAPE, AND DISTRIBUTION OF THE LARGE ELEMENTS.

The distribution of land and sea with its antipodal relations has always been fascinating and subject to much speculation. From the standpoint of isostasy, the Pacific sector is a basin because it is composed of denser material than the antipodal land sector, and it should, therefore, stand at a lower level. The perplexing question, then, is not a matter of why the basin is there, but a question of whether the sector is still actively subsiding or not. If it is still subsiding, what would be the effect on the earth's core and on the continental masses? Perhaps the most vital question of all is why should the Pacific sector be denser in the first place. These questions demand a thorough investigation of the earth's interior, a seemingly impossible task since first hand information is unobtainable. If we assume, however, that the major elements of the earth's surface reflect internal conditions, a toehold into the problem may be established, especially if we temper our deductions with seismological and magnetic information.

Data on the earth, its size, shape, and the distribution of surface features are given below along with the approximate location of the magnetic poles. It is believed that these are the factors that must be woven into a working hypothesis to answer the foregoing questions.

DIAMETERS AND RADII.[6]

Average radius of the earth = 3958 miles.

[4] Wegener, A.: op. cit., pp. 194-205.

[5] Daly, R. A.: 1926. Our Mobile Earth, Scribners, New York, pp. 306-307.

[6] Daly, R. A.: 1940. Strength and Structure of the Earth, Prentice Hall, New York, pp. 17-22. (Kms. converted to miles); p. 32 (equatorial diameters).

Polar radius of the earth = 3950 miles.
Average equatorial radius of the earth = 3963.3 miles.
Difference (equatorial-polar radii) = 13.3 miles.
Major equatorial diameter located in plane of 25° W-155° E.
Minor equatorial diameter located in plane of 115° W-65° E.
Difference (major-minor equatorial diameters) = .44 miles.
Average diameter of core = 4312.3 miles.
Average depth to core = 1802 miles (2900 km).

VOLUMES.
Earth = $259{,}727\times10^6$ cubic miles.
Core = $42{,}398\times10^6$ cubic miles.
Ratio of core to earth = 1/6.12.

MASSES.
Earth[7] = 6500×10^{18} tons (5.9×10^{27} gms.).
Core = 2146×10^{18} tons (assuming a density of 11).
Ratio of core to earth = 1/3.03.

DENSITIES.[8]
Surface average 2.67 (Granitic shell 9.3 miles thick = 2.7).
At 26 miles (42 Kilometers) = 3.32.
At 298 (−) miles (481) Kilometers = 3.69.
At 298 (+) miles (481 Kilometers) = 4.28.
At 1810 (−) miles (2920 Kilometers) = 5.56.
At 1810 (+) miles (2920 Kilometers) = 9.69.
At 3950 miles (6371 Kilometers) = 12.17.
Average for the core = 10.93.

AREAS.[9]
Total area of the earth = 196,910,400 sq. miles.
Total water area = 141,055,400 sq. miles.
Total land area = 55,885,000 sq. miles.
Total area of the core = 58,420,286 sq. miles.
Area of the Atlantic = 31,529,000 sq. miles (1/6 of earth total).
Area of the Pacific = 63,985,000 sq. miles (1/3 of earth total).
Area of the Indian = 28,357,000 sq. miles (1/7 of earth total).
Total land area east of African west coast = 38,000,000 sq. miles.
Total land area west of African west coast = 18,000,000 sq. miles.
Total land area east of Pacific bisectrix = 28,000,000 sq. miles.
Total land area west of Pacific bisectrix = 28,000,000 sq. miles.

7 Daly, R. A.: Strength and Structure of the Earth, p. 17.
8 Daly, R. A.: Strength and Structure of the Earth, p. 23.
9 Goode, J. P.: 1939. School Atlas, Rand McNally & Co., New York, pp. 174–175.

RELIEF.[10]

Average elevation above sea level = 2500 feet.
Average elevation below sea level = 14,200 feet.
Most frequent positive elevation = 1500 feet.
Most frequent negative elevation = 15,000 feet.
Average depth of Atlantic is less than Pacific.
Maximum relief of mid-Atlantic ridge = 18,000 to 20,000 feet.

LOCATION OF MAGNETIC POLES.[11]

North magnetic pole located at 70° 10′ N – 96° W.
South magnetic pole located at 72° 30′ S – 155° E.

ANALYSIS OF THE DATA.

It will be noted from a study of Fig. 1 that the Pacific bisectrix is essentially at right angles to the plane containing the magnetic poles, and that the plane of the poles lies wholly within the Pacific hemisphere. It will be observed also from the data above that the total land area east of the Pacific bisectrix equals the total land area to the west. The earth is highly asymmetrical with respect to a plane at right angles to the Pacific bisectrix, but essentially symmetrical with respect to the plane of the bisectrix. (The bisectrix does not pass half way between the projection of the magnetic poles because the south magnetic pole is at a higher latitude than the north magnetic pole.) What is the significance of this unsymmetrical land, sea, and magnetic distribution? Is it purely coincidence that the magnetic poles should be on the dense, Pacific side of the earth, and that the magnetic axis should be essentially at right angles to the Pacific bisectrix?

It is the writer's opinion that as the arrangement of the land and sea indicates an asymmetry of the earth's surface, so the magnetic poles indicate an asymmetry of the earth's interior. A number of years ago Bauer[12] called attention to the fact that 94 per cent of the earth's magnetism is due to internal conditions, and that only six per cent is due to external factors. If the earth's magnetism is mainly self-induced because of the earth's rotation, one would expect coincidence of the magnetic

[10] Nevin, C. M.: 1942. Structural Geology, John Wiley and Sons, New York, pp. 262-265.

[11] Goode, J. P.: School Atlas, p. 46.

[12] Bauer, L. A.: 1922. Chief Results of a Preliminary Analysis of the Earth's Magnetic Field; 1923. Terrestrial Magnetism and Atmospheric Electricity, Vol. 28.

poles with the geographic poles, or allowing for a polar wobble, one would at least expect the magnetic poles to lie in the same plane as the geographic. Neither condition is true. Therefore an internal asymmetrical condition is impossible.

In 1932 Fisk[13] noted that the most active centers of secular change (annual changes in magnetic declination) lie in the land hemisphere, and that the antipodal Pacific area has the least

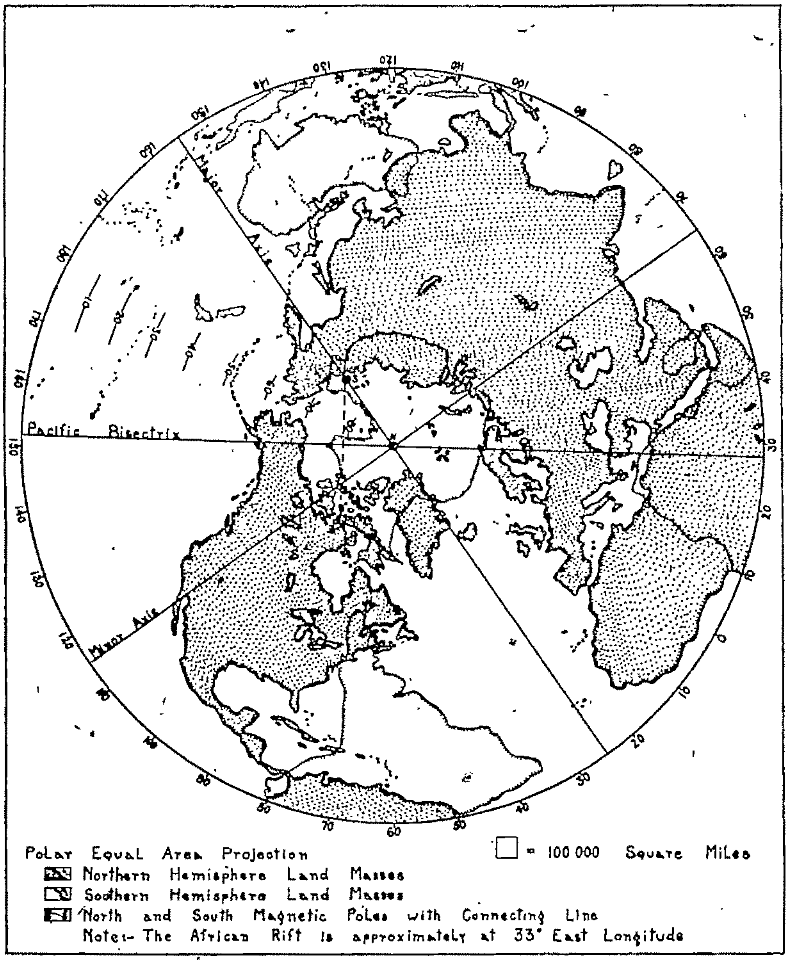

Fig. 1. Shows the distribution of land and sea with respect to major and minor axes, and the Pacific bisectrix. Note that the Pacific bisectrix is essentially at right angles to the trace of the plane containing the magnetic poles.

[13] Fisk, H. W.: 1932. The Unsymmetrical Distribution of Magnetic Secular Variation, Terrestrial Magnetism and Atmospheric Electricity, Vol. 37, No. 3.

secular change activity. He points out that this unsymmetrical distribution of magnetic secular variation

> is probably connected in some real, but at present unknown way with some phenomenon of the earth's interior, perhaps related to crustal movements or subcrustal adjustments which are more active in the hemisphere containing the greatest landmasses than in the opposite one.

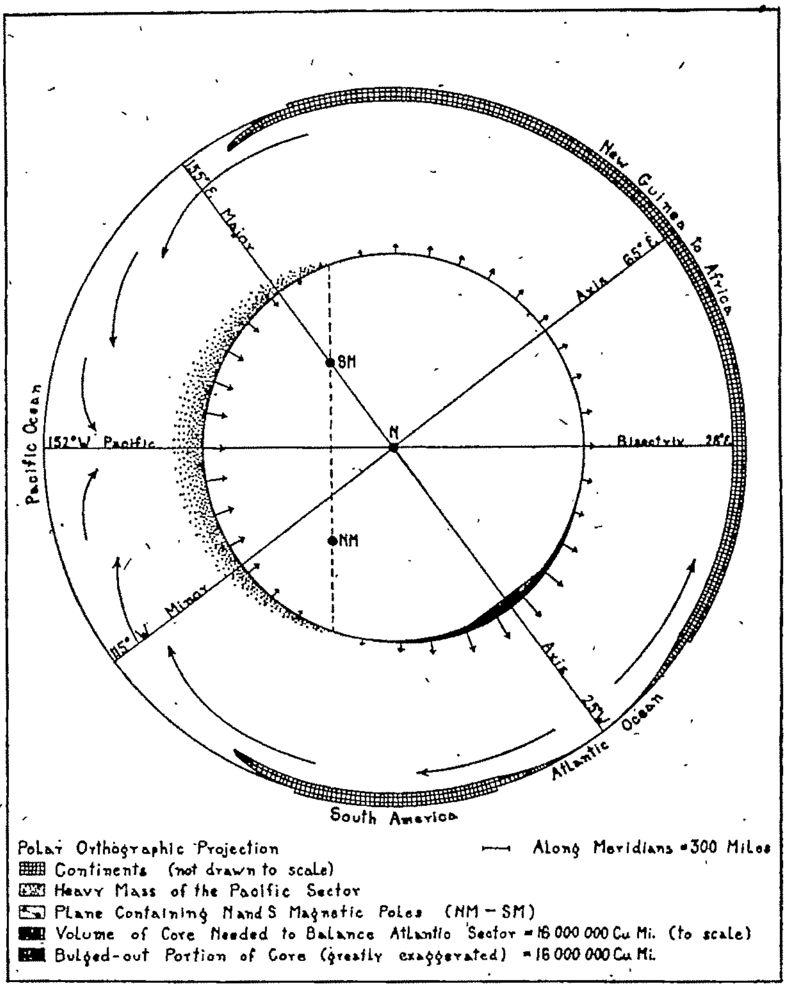

Fig. 2. Shows the core of the earth which is assumed to act and transmit pressure like a liquid. The inward directed radial arrows indicate the relative rate and direction of subsidence for the Pacific. The outward directed arrows represent potential and actual expansion of the core. Long arrows indicate horizontal displacements.

Fisk implies that the surface magnetic variations are due to some subsurface phenomenon presumably associated with the hemispherical asymmetry.

It has been noted that the magnetic poles lie in the Pacific hemisphere. Apparently this sector is more permeable to magnetic lines of force than the antipodal one. Since iron and nickel are highly permeable to magnetic lines of force, and since the earth's interior is supposedly high in these two elements, it is possible that a deep-seated zone of nickel and iron in the Pacific sector is channeling the magnetic lines through that area (stippled area in Fig. 2). If it is assumed that this zone lies directly above the core in the shell between 298 to 1810 miles below the surface, then the difference in permeability between it and the core may be due to a difference in the physical state of matter. It has been theorized that the core is a homogeneous mass of nickel and iron that reacts like a liquid to seismic waves, but that the surrounding shells do not act like a liquid.

Because of the demands of gravity, all heavy matter should be differentially attracted toward the earth's center. Therefore, if the shell next to the core is heavier in the Pacific sector than it is elsewhere, it should be subsiding toward the core, and with it the entire Pacific Basin.

According to Dutton,[14] who first proposed the term "isostasy," a planetary body whether it is homogeneous or not will be reduced to a condition of equilibrium by the force of gravity. If the body is homogeneous, the resulting surface will be perfectly smooth. If the body is not homogeneous then where the denser material is accumulated there will be a tendency for a depression, and where the lighter material is accumulated there will be a tendency to bulge. If the earth was born with a dense Pacific sector, then obviously the opposing half would be lighter and stand at a much higher elevation than the other. Thus the earth would be in isostatic equilibrium, and the moment of momentum for the Pacific sector would exactly equal that of a similar cross section for the opposing land sector. But if the Pacific area is subsiding as postulated above, then a redistribution of the lighter land area is necessary to maintain isostasy.

[14] Dutton, C. E.: 1889. On Some of the Greater Problems of Physical Geology, Bull. Phil. Soc. Wash., Vol. 11, pp. 51-64; 1925. Reprinted in Jour. Wash. Acad. Sc., Vol. 15, pp. 359-369.

If a symmetrical wheel is out of balance because a weight has been fastened to a spoke, it can be balanced by hooking an appropriate lead weight to the rim opposite the heavy mass. Now, as one slides the weight on the spoke toward the hub it will be necessary to split the lead weight exactly in half and move it in opposite directions along the rim to maintain a balance. Finally, when the heavy mass has reached the center of the wheel, the two halves of lead will have to be exactly 180° apart from each other. The wheel will then be in a set state of balance no longer requiring a shifting of masses along the rim. Does this analogy apply to the earth? If the Pacific sector is sinking toward the center of the earth, is the opposing land mass splitting up and moving in opposite directions, or have the masses already been shifted to a set state of balance?

From a study of Fig. 1 and the data listed under "Areas" one learns that the land masses are symmetrically disposed on either side of the Pacific bisectrix. This is as it should be if we consider the land area as analogous to the lead weight. But if a split has occurred, should not the split have been along longitude 28° E to divide the land mass exactly in half? According to Wegener, the split occurred just off the west coast of Africa, presumably along the Atlantic ridge. Thus the land mass to the west of Africa lacks some 20,000,000 square miles of being equal to that of the east. (See data above.) Nevertheless, the earth has not been thrown out of balance. Evidently some deep-seated interior change has occurred to make up for the missing 20,000,000 square miles to keep the earth masses isostatically in balance.

The precise shape of the earth as yet is not exactly known, but according to Helmert, Bowie, Berroth, Hirvonen, Heiskanen, and others[15] the earth's equator is slightly elliptical. Most of the computations put one end of the major axis through or slightly to the east of the mid-Atlantic ridge. The locations of the major and minor axes as given in Figs. 1 and 2 are taken from Heiskanen's latest work[16] (1938). From the data on the shape of the earth, we learn that it is a triaxial ellipsoid. Now if the earth as a whole is a triaxial ellipsoid bulged out along longitude 25° W, the core must also be a tri-

[15] Daly, R. A.: Strength and Structure of the Earth, p. 81.

[16] Daly, R. A.: Strength and Structure of the Earth, W. Heiskanen's work cited, pp. 81-82.

axial ellipsoid bulged out along longitude 25° W. Certainly a core 1/6 the size of the entire earth and 1/3 of its entire mass cannot assume a shape altogether independent of that of the earth. The question that now arises is, Why is the mid-Atlantic diameter longer than the one at right angles? The answer is that the bulge is necessary to make up for the lack of some 20,000,000 square miles of land that should lie to the west of Africa. The moment of momentum for any half of the earth must be exactly equal to the moment of momentum for the other half if the earth is to rotate smoothly like a balanced wheel.

THE MECHANICS OF CONTINENTAL DISPLACEMENT.

If the assumptions based on the analysis of the data are accepted, it is possible to postulate a single working hypothesis that will serve to explain the major features of the earth. The basic assumption is that the Pacific basin is subsiding, and that the core of the earth behaves like a liquid.

In the example of the wheel analogy, the lead weight had to be split exactly in half and moved apart as the spoke weight was shifted toward the hub. The analogy served its purpose in conveying an idea, but it does not fit perfectly, because the wheel was too strong, and did not possess enough gravitation to overcome its own strength. Hence the masses had to be shifted by hand. But the earth is large enough so that gravity will overcome the strength of any feature as large as a continent or ocean basin. So as the heavy Pacific basin sank, the land mass centered in Africa split, but not into two equal parts. This is because the core of the earth possesses no strength, and the Pacific pressure was not transmitted in one direction toward longitude 28° E, but in all directions with equal intensity (Fig. 2). Hence the break was determined by a direction of easy relief. This was along the present line of the Atlantic ridge and not along the Pacific bisectrix. North and South America were displaced westward by the bulging core and at the same time were drawn in toward the collapsing Pacific Basin (Fig. 2). The height to which the core bulged was in proportion to the amount of land displaced. This, as has previously been pointed out, amounted to a mass having an

area of about 20,000,000 square miles. Africa and Eurasia were displaced a relatively small amount to the east. Wegener and others also claim a large eastward displacement of Australia.

To summarize the hypothesis, it can be said that the continental displacements are due to a subsiding Pacific Basin which exerts pressure on a liquid-like core. The pressure on the core is relieved by a bulging-out action in a direction of easy relief. The combined bulging out and subsidence will displace the crust away from the direction of easy relief toward the collapsing floor of the Pacific.

CHECKING THE HYPOTHESIS.

Computations as to the volume of bulge necessary to compensate for 20,000,000 square miles of land should give a value comparable to the difference between the length of the major and minor axes. This difference amounts to about a half mile according to Heiskanen's 1938 value.

In terms of the geoidal surface (sea level surface), land has a most frequent elevation of 1500 feet and ocean basins a most frequent depth of 15,000 feet. This is a difference of approximately three miles. Using a value of three miles to compute the volume of rock in 20 million square miles, a value of 60,000,000 cubic miles is obtained. But if it is assumed that the geoidal surface is an equilibrium surface, then, the weight of water that 60 million cubic miles of rock will displace must be subtracted from the total weight of rock. This will give the approximate weight of rock that the bulge in the core must compensate. Surface rocks are approximately 2.7 times heavier than water. Therefore, the weight of water that 60 million cubic miles of rock will displace is equal to the weight of about 22 million cubic miles (60 million divided by 2.7). Thus, approximately 38,000,000 cubic miles of rock must be balanced. The moment of momentum for 38 million cubic miles at the earth's surface must equal the moment of momentum for the bulged out core. Moment of momentum equals mass $\times$ radius $\times$ velocity. Since the angular velocities are equal, the velocity factor cancels out. Therefore the volume of the bulge equals 38 million $\times$ 2.7 $\times$ 4,600 million $\times$ 3963 divided by 11 $\times$ 4,600 million $\times$ 2156 or around 16 million cubic miles. (4,600 million = number of tons in a cubic mile of water; 2.7 = average density of surface rocks; 3963 =

average equatorial radius; 11 = average density of the core; 2156 = average radius of the core). Sixteen million cubic miles is equal to a segment of core about 35 miles high and 420 miles in radius. Such a segment is shown approximately to scale in Fig. 2. But when this volume is spread out over one-sixth of the area of the core, it amounts to a thickness of only 1.7 miles (the Atlantic is one-sixth of the area of the earth). This value is greater than the difference between the major and minor axis, but it is not unduly large. Three factors were not taken into consideration in the computations, namely:—(1) The fact that the Atlantic is shallower than the Pacific (the 3 miles thickness may be too great); (2) The mass of the mid-Atlantic ridge and other sialic areas was not subtracted (the mid-Atlantic ridge is roughly 9000 miles long and rises as much as 18 to 20 thousand feet above its base).[17] (3) The matter above the core may be thinned out like a supratenuous fold so that the ellipticity of the earth is not a perfect reflection of the ellipticity of the core.

As the dense matter of the Pacific sinks below the level of the core at 2900 km., it will probably be assimilated by the core. This will tend to make the core grow larger, but there must be a limit to the size it can grow and still behave like a liquid. Whether this limit has been reached is not known, but as the nickel and iron of the Pacific sector is lost to the core certain magnetic changes will undoubtedly result. Can it be that this is in part responsible for the secular magnetic activity? Also, is it possible that any bulged out portion of the core will lose its liquid behaviour and become more permeable to magnetic lines of force?

Since Africa is directly opposite the Pacific it must have been the center (equatorial plane) of the land that counterbalanced the Pacific sector. If this is true, it probably represents that part of the earth that had the highest initial elevation, and also the lowest initial density. Therefore Africa as a whole should be the most positive land mass in the world, and it apparently is. The total amount of young rock for this area is less than that of any other continent. This is also the area from which the land masses broke away to counterbalance the sinking Pacific sector; hence it is not surprising to find the largest rift in the world located here. Whether the African rift represents a present, active, parting of the

[17] Nevin, C. M.: Structural Geology, p. 266.

ways, or a split that has been abandoned, has not yet been determined. It is interesting to note that Africa was not displaced very far to the east with respect to the mid-Alantic ridge. Is this because there is another bulge in the Indian Ocean that wedged Australia eastward and fixed the position of Africa?

The Pacific Basin is noted for its intense volcanic activity and for its deep-seated earthquakes. This should not be out of harmony with respect to a collapsing basin. The wedging apart of land in an area of bulge does not necessarily mean that the Pacific end of the land will be drawn into the Pacific Basin at a rate proportionate to the wedging. Because of elasticity, the crust of the land does not respond as an integral unit. In a like manner, it is doubtful that the floor of the Pacific responds as a unit especially in view of the deeps, swells, and the lines of volcanic activity. Some areas probably sank more rapidly than others so that both tension and compression could be active. The lines of vulcanism probably represent tensile areas. Since the deeper zones would be drawn into the basin more rapidly than the shallower ones, underthrusting may be possible and the slippage of the deep zones past the shallow ones may be responsible for the deep-seated quakes.[18]

According to Gutenberg,[19] the Pacific Basin differs from that of the Atlantic and Indian in that the latter two are completely floored by a layer of sial. This conclusion is based upon seismological data. It indicates a thickness of sial of about 25 to 30 miles for the land but only a thickness of about 15 miles for the Atlantic and Indian floors. This is not at variance with the idea set forth in this paper. It has been assumed that the Pacific Basin is different from the Atlantic and Indian in that it is a primary basin. Sial should floor secondary basins, because they were originally the land areas from which "the spreading," as Gutenberg puts it, originated. The sial of such basins should be thin because it represents the stretched-out areas. The thinning of sial toward the Pacific is due to the drag of the sima as it is differentially drawn into the Pacific Basin (Fig. 2).

[18] Gutenberg, B.: 1936. Structure of the Earth's Crust and the Spreading of the Continents, Bull. G. S. A., Vol. 47, pp. 1601-1605.

[19] Gutenberg, B.: Structure of the Earth's Crust and the Spreading of Continents, pp. 1609-1610. ("Fliesstheorie" and Conclusions.)

SUMMARY AND CONCLUSIONS.

In summary, it may be useful to give a hypothetical history of the early development of the earth. If the earth was torn or hurled out of the sun let us say according to the Planetesimal hypothesis, it was probably born with one side heavy. In fact it is inconceivable to suppose otherwise, for certainly the sun's density must increase with depth. If the earth's interior was highly fluid in this early stage, segregation of the heavy matter toward the earth's center would have been rather rapid, but according to the idea presented in the hypothesis this could not be true. Let us assume, therefore, that the internal viscosities were high and that deep seated segregation was slow. This means that rapid settling of heavy matter was only possible in the outer portion of the earth and that as greater depths were reached, the rate of settling slowed considerably. (Increasing viscosity and decreasing gravity.) Daly states that under such a condition the earth's surface would be smooth although its interior would be asymmetrical[20] with respect to density. He believes that when the crust finally froze the internal asymmetry was reflected in differences of relief. The hemisphere that contained the dense matter became the Pacific Basin, and the antipodal area the original land mass. As the Pacific Basin subsided, matter would have to be shifted toward the Pacific to maintain a balance between the land sector and the basin. This was accomplished at first by erosion and deposition of sediments outward from the land toward the Pacific, but eventually erosion became inadequate because of the lowering of stream gradients. (Elevations decreased and streams lengthened.) Finally, the original land mass had to be broken up and displaced to maintain equilibrium of rotation. This was brought about in the manner outlined in the hypothesis and, according to Wegener, began in Mesozoic times.

This investigation has been based upon a study of the major features of the earth as viewed from a polar perspective. Much of the discussion centered around the Atlantic and its ridge. This does not preclude the existence of other minor bulges, nor does it imply that all bulges trend north and south.

It is hoped that the paper will serve to stimulate further investigation. Work should be done in correlating magnetic, gravity and seismic surveys.

[20] Daly, R. A.: Our Mobile Earth, bottom of p. 305, "The ancient slidings . . . the globe is assumed to have become unsymmetrical after its solidification."

KANSAS STATE COLLEGE,
MANHATTAN, KANSAS.

OBITUARY.

SIR ARTHUR SMITH WOODWARD.

The death, on September 2, 1944, of Sir Arthur Smith Woodward at the age of eighty removes one of the great figures in the history of paleontology. Three generations of colleagues have been inspired by his example as a scientist and helped by his interest as a friend.

Smith Woodward was born in Macclesfield on May 23, 1864. After attendance at Macclesfield Grammar School and Owens College, Manchester, he obtained a second-class assistanceship in the British Museum at the age of eighteen. He advanced to Assistant Keeper of the Department of Geology in 1892 and became Keeper in 1901 holding that position until his retirement in 1924. During his second year at the British Museum he attended and absorbed a series of lectures on fossil fishes by the great 19th century authority on this subject, R. H. Traquair, and was so inspired that he immediately began and throughout the rest of his life continued to devote most of his outstanding research talents to this subject.

Between 1889 and 1901 he published the four volume "Catalogue of the Fossil Fishes in the British Museum (Natural History)." No one since has attempted so complete and thorough a synthesis of paleoichthyology and this classic work is a main basis for the whole subsequent development of that science. It combines concise, accurate, workable diagnosis with a broad and masterly review of phylogenetic trends and evolutionary principles. A fellow student (W. K. Gregory) states that Smith Woodward's general concepts of the classification and history of fishes still stand, in their essentials, and even form a happy contrast with some of the most recent attempts to arrange these groups. Besides about 200 shorter papers on this subject, Smith Woodward published several other large and basic memoirs on fossil fishes, notably "The Fossil Fishes of the English Chalk" in 1902-1912.

As a one-man department of vertebrate paleontology during much of his career, Smith Woodward accompanied his specialization on fossil fishes with broad interest and general competence in the study of other fossil vertebrates. In 1890, with C. D. Sherborn, he published a catalogue of all known British fossil vertebrates and in 1898 appeared his "Outlines of Vertebrate Palaeontology for Students of Zoology." This was a radical departure from other available texts, virtually unreadable Teutonic compilations, in being inherently interesting, with judicious stress of the truly significant and omission of the relatively insignificant, and in being based in

larger measure on direct, personal acquaintance with the fossils, themselves. He later also collaborated in English revision of the leading German textbook (Zittel), which is nevertheless decidedly less useful for teaching than was Smith Woodward's own book. After his retirement he planned a revision of the "Outlines," but, to the regret of all, this remained unfinished.

In 1896 and in 1907 Smith Woodward visited Argentina and became greatly interested in the remarkable discoveries then being made by Roth, the Ameghinos, and others. He also did much to publicize the amazing results of Argentine paleontology and no little to correct the occasional excesses that arose from the enthusiasm of the South American students.

After the discovery of Piltdown Man by Dawson in 1911, Smith Woodward collaborated in further successful research at the site and he produced a reconstruction of the skull. His interest in ancient man, thus aroused, remained active and he wrote some 25 short papers and summarizing addresses on this subject. This work was competent but cannot be ranked as of topmost importance in its field. It is unfortunate that Smith Woodward's popular acclaim arose from his almost accidental association with this one sensational discovery, wholly outside the field which he had made truly his own and on which his real evaluation in scientific history will rest.

During his keepership, Smith Woodward greatly expanded the fossil vertebrate collection in the British Museum and also succeeded in making it considerably more representative of the whole subject than it had been under Henry Woodward and earlier keepers. Not essentially a field naturalist, his only important field work was at Pikermi, Greece, in 1901—collecting fossil mammals, which is rather curious in view of the fact that he was then already the world authority on fossil fishes and had done little original work on mammals. In general, he built up the museum collections by purchase and donation and not by scientifically conducted museum expeditions, continuing the tradition of closet natural history that has been the one weakness of vertebrate paleontology at the British Museum. Nevertheless his efforts kept the collections among the greatest in the world.

There has recently been considerable interest in the productivity of scientists at various ages, and in this respect Smith Woodward's career is an interesting example, although apparently an atypical one. In volume, importance, and originality his total production ranks near the top in his science. He was decidedly precocious, publishing his first paper at the age of 18 in spite of a minimum of previous technical training. When he was 23 he was already well into what must probably be considered his greatest work and he was only 28 when his hundredth publication appeared. From about the

time he was 30 his productivity, as regards original research, declined steadily until his last paper in 1942, at the age of 78. By the time he was 40, all but one of his really major contributions were completed, and that one was then well along toward completion. Even his textbook, which is intellectually perhaps his most mature production, was issued when he was only 34. The research of his last 40 years was far from negligible. On the contrary it includes some very important studies (among them those on Piltdown man), but it is clear that his output decreased greatly in quantity and did not tend to broaden much in scope or to become significantly deeper in philosophic quality after he reached an age when most paleontologists are just beginning to be well established professionally.

Smith Woodward's influence on paleontology cannot be judged solely on the basis of his own researches, great and extensive as they were. He continued and increased the British Museum's fine reputation as a research center by placing all its collections, described or undescribed, unreservedly at the disposal of qualified students from all over the world. In his wide travels he made friends of most of the paleontologists of all countries, who were given a warm welcome and entertained if they, in turn, visited England. He corresponded voluminously and had an inspiring enthusiasm for the work of all his colleagues.

Inevitably his many accomplishments and appreciated personality brought honors far too numerous to list completely. He was four times an honorary doctor, from such diverse universities as Glasgow and Athens. He was a Fellow of the Royal Society and of all other British societies pertinent to his profession and was knighted by the King. He received many prizes and medals, including the Lyell, Wollaston, and Royal Medals in England and the Hayden and Thompson Medals in the United States. He was a corresponding or foreign member of some twenty non-English scientific societies, including the Geological Society of America, and he held office in many British societies, among them the Royal Society, the British Association, the Linnean, Geological, and Zoological Societies, and the Geologists' Association.

We may now repeat with still stronger and definitive evidence what his former chief, Henry Woodward, could already say of Arthur Smith Woodward 29 years ago: "Few scientific men can lay claim to so large a share of solid work in his own special department or to have done more individually to advance geology and paleontology, the sciences to which he has devoted his life."

GEORGE GAYLORD SIMPSON.

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* This index contains the General Heads: BIOLOGY, CHEMISTRY, GEOCHEMISTRY, GEOLOGY, GEOPHYSICS, MINERALOGY, PALEOBOTANY, and PALEONTOLOGY; under each the titles referring thereto are included.

Initial capitals are in general used for the title of books noticed.

CHEMISTRY.

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